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No. XIV

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CHRISTIAN A. RUCKMICK

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PREFACE

In the year that has passed since the last volume of Iowa Studies was published the investigations presented in this volume have been completed and prepared for publication. They represent researches done in partial fulfillment of the requirements for the doctorate and in a few cases for the master's degree. The investigations continue the systematic trend developed in previous volumes and thus offer their contributions to the fields of research in which the psychological laboratories at the University of Iowa have for a long time been interested.

In the realm of the psychology of music Dr. Williams presents a critical survey of the tonoscopic technique for testing accuracy in singing. He makes suggestions for the most effective means of using this technique and describes noteworthy improvements in the apparatus itself. Dr. Tiffin gives a detailed account of the vibrato which has now been more rigorously analyzed and controlled than in previous studies. This thesis makes a marked advance in the comprehension of artistic singing.

In the allied field of auditory percepts Dr. Hauge offers a contribution in the analysis of phenomena connected with the beating complex. This study continues a previously published paper and clearly shows the relation of the beat to the respective intensive and qualitative changes of the primary sources. The problem that Dr. Mathieson attacks is a still more baffling one and invites further investigation. She tried to discover under what conditions the motion of sounds could be perceived. In a few instances she succeeded in obtaining movement and even the pure *phi-phenomenon.* The study presented by Dr. Triplett concerns itself with temporal percepts in the auditory field. On the basis of an analogy from the well-known data in the perception of visual extents, she investigated the question of filled and unfilled temporal intervals in connection with auditory stimuli.

Minor studies include a preliminary investigation by Dr. Smith

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done in post-graduate residence during a leave of absence, on variations in the galvanic response. D. W. Dysinger describes a comparative study which utilizes both the impressive and the expressive procedures in the investigation of affective tone. Another introductory study by B. Blackburn sought to analyze the voluntary movements of the vocal mechanisms in normal and defective speech. To these experimental researches the editor has added a theoretical discussion of his own which attempts to synthesize several of the theses which have been recently done under his direction.

These studies present a rough cross-section of the work which is in process in our laboratory. The problems unfold themselves progressively either on higher systematic levels or through more intensive analyses as techniques are refined and improved. While the investigations have been under the guidance of members of the Staff, no small amount of ingenuity and persistent effort has come from the experimenters who have done the work. The Editor wishes here to record his appreciation of the serious zeal of the students who saw more in their problems than a requirement for the higher degrees. Many of them are continuing further research issuing from these problems after the conditions for the doctorate have been met. He also acknowledges the willingness of the authors to abridge their respective contributions and otherwise to conform to the standards and traditions of the Iowa Studies, even when thus faced with serious handicaps in presenting the material. The fellowship of such workers in the experimental field is an invaluable compensation for the task of editing the series.

THE EDITOR

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VOLUNTARY MOVEMENTS OF THE ORGANS OF SPEECH IN STUTTERERS AND NON-STUTTERERS [1]

by

BRUCE BLACKBURN

I. Introduction. Speech is a highly integrated activity of several complex structural groups and requires extreme nicety of coördination in the musculatures involved. When it is remarked that each of these structures has as its primary biological function some other than that of speech, it can be appreciated that the process of integration of the vocal function must allow great opportunity for maladjustment.

In planning investigations of the vocal mechanisms as it is concerned in abnormal speech, it is valuable to consider the two main modes in which such abnormalities may arise:

(1) Speech defects may be generated by specific structural faults of the peripheral or central speech mechanisms, resulting in such disorders as "tongue-tie," whole or partial paralyses, or motor and sensory aphasias. Such disorders, excepting sensory aphasia, might reasonably be expected to result in imperfect performance of structures in non-speaking as well as in the performance of speech.

(2) Speech defects may be symptomatic of a more general functional disorder, resulting possibly in functional aphasias, paralyses, tics, or emotional blocking. Among the causes might be included educational deficiencies, poor motor or auditory imagery, or a functional opposition in the central nervous mechanisms brought about when an acquired motor dominance of one cerebral hemisphere is superimposed upon a native or early established dominance of the other hemisphere. Speech disorders of this class might have their genesis and continuance in the

[1] This investigation was made under the direction of Dr. Lee Edward Travis.

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psychological setting of speech. In this case it might be expected that abnormalities in the performance of the structures would be found only during speech, except in the case of opposed cerebral dominance.

II. Historical. There are available many detailed analyses of the performance of peripheral speech mechanisms of stutterers during attempts at speech. *Halle* (6) found tonic and clonic spasms of the diaphragm and generally poor breathing economy. *Ten Cate* (7) reported that the period of expiration was shorter in stutterers, and that inspiration was protracted, quite the reverse of the situation among normal speakers. *Gutzmann* (4) found clonic and tonic spasms of the diaphragm and temporal opposition of costal and abdominal breathing movements. *Travis* (8) described a dysintegration of various motor units in speech including complete antagonism between the action of thorax and abdomen, prolongation of inspiration, clonic and tonic spasms of the several motor units. *Fletcher* (2) found retardation of inspiration, opposition of costal and abdominal breathing movements, and tonic spasms of the abdominal musculature in breathing. *Fletcher* observed that eccentricities of breathing often tend to become stereotyped in individual cases.

These investigations hardly touch upon a point which should be important in establishing the mode of genesis of stuttering. Does the speech mechanism of the stutterer exhibit any abnormalities of performance in movements other than those of speech? The only practicable method of determining the significance of the psychological setting in causing the functional dysintegrations among speech structures is to eliminate it entirely from the experimental procedure. There have been few investigations in which performance of the speech mechanisms in movements other than those of speech has been tested.

Fletcher and *Ten Cate* concluded that stutterers present no permanent peculiarities of (involuntary) breathing outside of the speech situation. *Gutzmann* (5) found clonic and tonic spasms of the diaphragm in stutterers. This was also found, however, in many normal speakers under the experimental conditions em-

ployed. *Anderson* (1) compared the performance of stutterers and normal speakers in several tests of voluntary motor activity. His data seem to show very slight differences, but his general conclusion was that stutterers differ from normal speakers in "certain types of motor reactions." Tests of the speech structures were not included in this study.

III. Aim of the present investigation. Speech depends upon the delicate functional integration of two main structural groups: The peripheral central speech mechanism, previously defined. Dysintegration of speech coördinations within either of these groups occurs in either, or both, of two causal modes:

1. The incoördinations may be a function of specific, localized defects or lesions of the central or peripheral speech mechanisms; in this event, excepting the case of sensory aphasias, the defect should be manifested in *any* activity of the damaged structure, quite aside from actual speech.
2. The incoördinations may be symptoms of a more general, functional disorder; in this case the motor peculiarity of the speech mechanisms should also be demonstrated in *any* of its activities, outside of speech proper, unless the functional disorder has its origin in the psychological setting of the speech situation.

These premises being accepted as valid, it was proposed to secure objective records of the strictly voluntary performance of several of the units of the peripheral speech mechanism, the speech situation being carefully excluded during all recorded performance. The primary purpose of the study was to analyze and compare the performance of stutterers and normal speakers throughout the range of the tests employed. Voluntary, rhythmical movements of the diaphragm, the tongue, the lips and the lower jaw were recorded and studied. As a check against the performance of the vocal structures a simple tapping test involving rhythmical arm-hand coördinations was used.

IV. Apparatus. The kymographic recording technique was utilized for all tests. A kymograph mounting a long recording paper and electrically driven at a constant speed of 11 mm. per sec. was used. Approximately four minutes of performance were recorded on each paper. The Marey recording tambours were equipped with relatively long writing styli, affording considerable amplification of the changes registered in the receiving

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apparatus. A time line in sec. was furnished by a signal-magnet in circuit with a pendulum spark-chronoscope.

Voluntary movements of the tongue were registered on a simple device utilizing principally a modified tambour, connected with another recording tambour by rubber tubing 4 mm. in diameter. The tip of the tongue was placed against a metal cup connected by a short rod with the diaphragm of the registering tambour. By means of this device, to and fro movements of the tongue were recorded without interference from any other source. A Sommer pneumograph connected with a recording tambour was used for registering and recording movements of the diaphragm. Care was taken to adjust the pneumograph about the costal region.

Voluntary movements of the lower jaw were recorded by placing a small, heavy walled rubber bulb, connected with a recording tambour, between the teeth. This device was very sensitive to movements of the jaw. Movements of the lips were recorded by the use of a very soft and pliable rubber bulb, which was placed firmly against the lips. This device was also extremely sensitive.

In the arm-hand coördination tapping test the *O* was instructed to tap with the index finger of either hand on the diaphragm of a modified tambour connected with a recording tambour. During all tapping tests the arm was unsupported. Bimanual tests were made on each *O*.

V. Procedure. *O* was seated in a straight backed chair with his back turned to *E* and the recording apparatus, and the testing devices were adjusted to the appropriate level. Each such device was explained and demonstrated to prevent any uneasiness or disturbance on the part of *O*. The types of performance were demonstrated by *E*, and before any records were made *O* was allowed approximately one minute for practising each test. In each test *O*s were asked to carry on the movements indicated just as rhythmically and regularly as possible. A demonstration rhythm approximating three per sec. was used, but *O*s were allowed to set and maintain their own rates. The point was

stressed that the rhythm selected was to be maintained as nearly as possible throughout the tests.

Many of the tests produced rapid local fatigue, notably the tests of voluntary rhythmical panting and voluntary tongue movements. Since fatigue is an individual variant, it was felt that to set arbitrary intervals of rest for all *O*s, with no reference to any individual, would be unfair. Therefore *O*s were instructed to rest during any test when they felt that fatigue was interfering with the regularity of the performance. The time of onset of fatigue was found to vary widely among the *O*s. In the case of stutterers, approximately four minutes of actual performance in each of the five tests was recorded. No more than eight minutes of performance was recorded at one sitting. Two minutes of performance in each test was recorded for each normal speaker. Tests were made in a quiet, well ventilated room, with no one present except *E* and *O*. It was carefully explained to each *O* that no speech would be required. This was done in order to prevent any speech anxiety on the part of stutterers.

VI. Observers. Thirteen stutterers were included in the experimental program. Two of them were female, both adult. Of the eleven male stutterers eight were adult, and three were under fourteen years of age. All stutterers were in attendance at the speech clinic. The majority were at a very early stage of speech therapy. Fourteen normal speakers were tested. All were adult university students, selected at random. Only two had more than a very superficial knowledge of the nature of the investigation. One was female.

VII. Data. In order to approximate completeness, the study of test results included both quantitative and qualitative analyses. Since the aim of all trials was to discover the ability of the *O*s in performing voluntary *rhythmical* movements of certain peripheral speech organs, the chief quantitative variable to be recognized was the *regularity* of performance. It was decided that the degree of regularity could best be described by obtaining the standard deviation in the number of movements performed from second to second. To secure this measure samplings of

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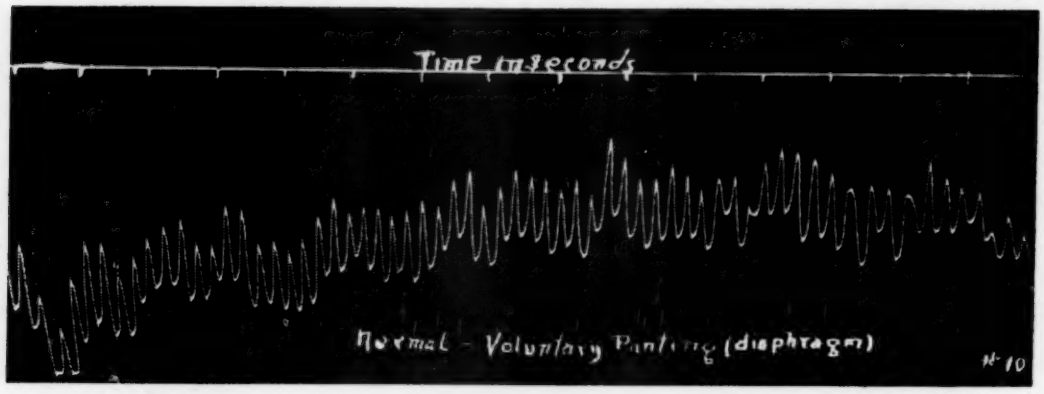


FIG. 1

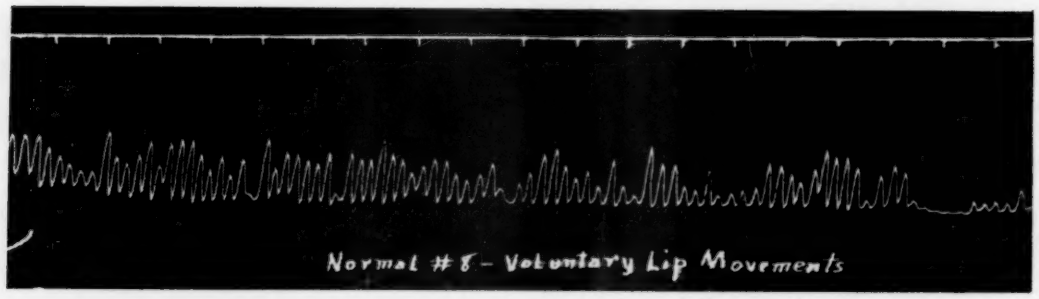
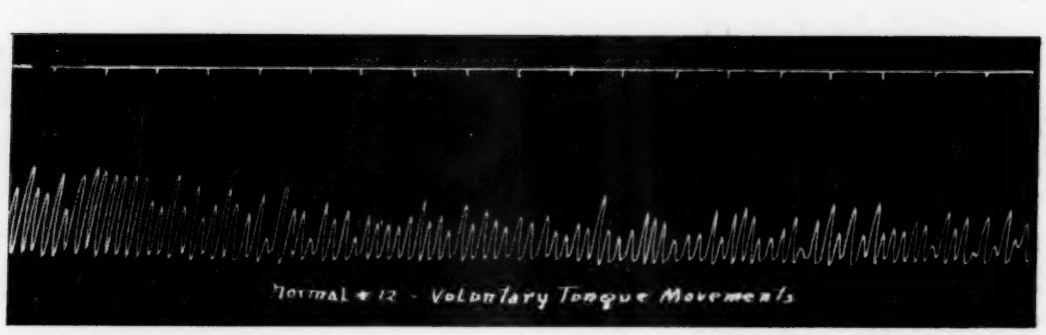


FIG. 2



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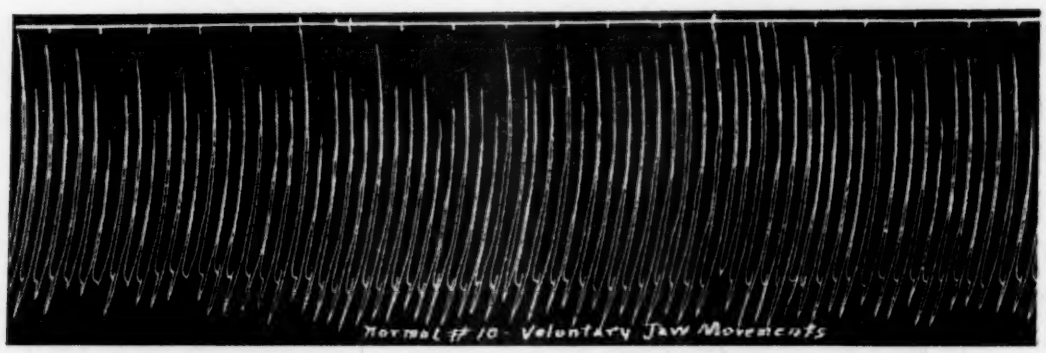

FIG. 4

PLATE I

performance were taken, consisting of the number of movements in every *fourth* second. In order that the measures thus secured in the separate classes of performance might be reduced to a common value, it was, of course, necessary to consider the *average rate* of performance in each. This condition was satisfied by utilizing Pearson's coefficient of variation, $V = \frac{100\sigma}{\text{Ave.}}$, in which V is the coefficient of variation. The following tables summarize the quantitative findings of the study.

Comparison of Table I and Table II reveals the fact that the standard deviations in rate of voluntary performance of speech structures was consistently greater in the case of stutterers. This fact is more clearly displayed in Table III. Variability in the rate of performance is particularly greater in voluntary movements of the diaphragm and tongue. Table IV compares the performance of stutterers and normal speakers in voluntary movements of non-speech structures (tapping test). Very little difference is noted, all *O*s exhibiting a high degree of regularity in performance.

The records show a great range of qualitative variation in the performance of stutterers. It might almost be claimed that each individual displayed a unique type (2). In the interests of classification it was considered worth while to designate certain types of performance which roughly differentiate certain groups among the stutterers. In Plate I, Figs. 1, 2, 3 and 4, are presented samples of voluntary movements of speech structures in normal speakers. The performance of normal speakers in general is characterized by a high degree of regularity. Plate II, Fig. 1, illustrates one type of performance found in stutterers, characterized by periodic groupings of relatively vigorous movements at a rate of about one group every two seconds. At fairly regular intervals are found periods of scarcely any activity. During the performance these periods were marked by an outward appearance of effort. These characteristics were particularly apparent in the voluntary movements of diaphragm and tongue in certain stutterers.

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TABLE I. *Data from stutterers*

		1	2	3	4	5	6	7	8	9	10	11	12	13	
O															
Diaphragm	Ave.	3.93	2.89	4.00	3.86	4.00	3.50	1.86	2.85	3.01	2.25	2.95	2.91	2.93	
	σ	.347	.9922	.845	.325	.813	.417	.643	.567	.149	.834	.201	.763	.726	
	V	8.8290	34.320	21.130	8.419	20.424	11.343	34.569	19.900	4.950	37.066	6.810	26.219	28.191	
Tongue	Ave.	5.57	5.10	4.94	7.15	4.70	5.71	5.13	6.25	3.82	4.95	3.77		3.35	
	σ	.506	.754	.328	1.012	1.030	.507	.848	.955	.603	.618	.534		.742	
	V	9.084	14.784	6.842	14.154	21.915	8.879	16.530	15.280	15.785	12.444	14.164		22.148	
Jaws	Ave.	5.25	4.00			2.92	3.46		2.85	3.47	3.45			2.53	
	σ	.323	.201			.338	.152		.741	.182	.426			.304	
	V	6.152	7.025			11.575	3.815		26.000	5.242	12.348			12.025	
Lips	Ave.	5.30	3.93			3.00	3.45		3.50	3.65	4.00			2.85	
	σ	.458	.506			.204	.150		.626	.404	.707			.295	
	V	8.641	12.850			6.800	4.347		18.171	11.068	17.675			10.351	

TABLE II. *Data from normal speakers*

O		1	2	3	4	5	6	7	8	9	10	11	12	13
Diaphragm	Ave.	5.59	4.58	4.19	5.64	3.06	3.83	3.10	4.41	3.20	4.20	3.17	3.62	2.88
	σ	.218	.186	.243	.225	.230	.471	.131	.283	.355	.204	.254	.201	.447
	V	3.900	.406	5.800	3.989	7.516	12.300	4.225	6.417	11.093	4.952	8.012	5.552	15.528
Tongue	Ave.	7.31	5.15	3.64	4.30	5.03	4.74	3.20	5.10	2.61	4.87	4.87	5.24	3.66
	σ	.299	.312	.307	.331	.441	.414	.019	.115	.178	.339	.360	.131	.441
	V	4.090	6.060	8.434	7.696	8.767	8.312	.593	2.254	6.820	6.940	7.392	2.500	12.049
Jaws	Ave.		4.62					4.93	3.65	3.01	4.42	4.06	4.41	3.78
	σ		.216					.153	.231	.235	.168	.105	.221	.445
	V		4.678					3.103	6.356	7.807	3.801	2.568	5.011	11.772
Lips	Ave.		4.89					4.08	3.96	3.50	4.51	3.12	5.03	3.93
	σ		.204					.300	.220	.201	.154	.201	.200	.342
	V		4.170					7.353	5.555	5.742	3.402	6.442	3.984	8.702

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TABLE III. *Comparison of the performances of stutterers and normal speakers in terms of the coefficient of variability*

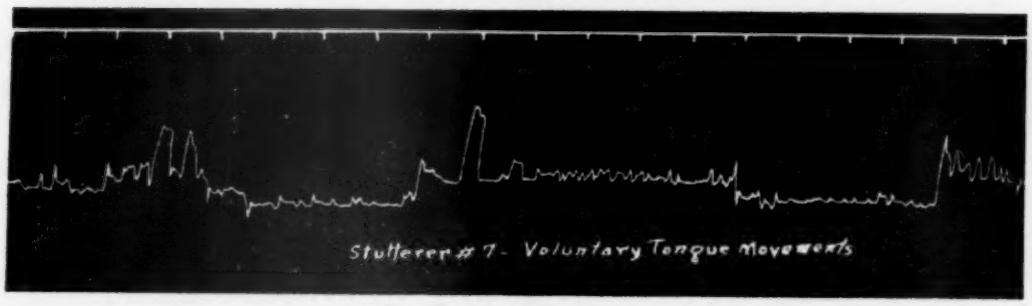
Speech Structures	Stutterers	Normal Speakers
Diaphragm	20.118	6.945
Tongue	12.488	5.993
Lips	10.523	5.639
Jaws	11.238	5.667

TABLE IV. *Comparison of the performance of non-speech structures of normal speakers and stutterers*

	Stutterers				Normal Speakers			
O	Right hand		Left hand		Right hand		Left hand	
	Ave.	σ	Ave.	σ	Ave.	σ	Ave.	σ
1	3	0	3	0				
2	3	0	3	0	4	0	4	0
3	2.6	.213	3	0				
4	4	0	4.5	0	5.4	0	4.2	.121
5	5	0	5	0	3.5	0	3.5	0
6	4.13	0	4	0				
7	3.38	.216	3	0	2.5	0	2.5	0
8	2.5	0	2.5	0	5	0	5	0
9	4.5	0	4.6	0	5	0	5	0
10					5	0	5	0
11	3.93	.463	4	0	4.5	0	4	0
12					4.3	1.41	4.2	.164
13	4.50	.086	5.08	.186	3.5	0	3.5	0
Mean σ		.108		.0169		.014		.028

Plate II, Fig. 2, a record of voluntary tongue activity, illustrates a second type of performance. Periods of extremely rapid but fine movements are interrupted by relatively coarse and prolonged contractions. This type was confined, for the most part, to movements of tongue, lips and jaws. Plate I, Fig. 3, exhibits a type of performance characterized by general retardation; muscular activity throughout is weak. In Plate I, Fig. 4, a record of voluntary panting, is found a type of performance in which control seems to be lacking to a great extent. Tonic spasms are

FIG. 1



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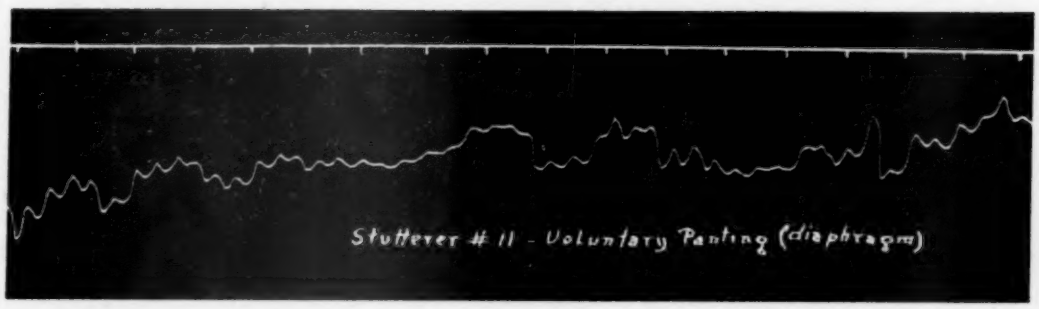

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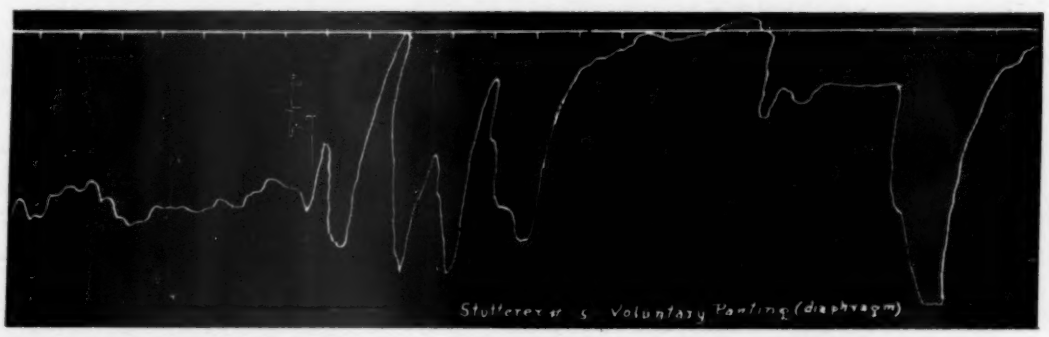

FIG. 4

PLATE II

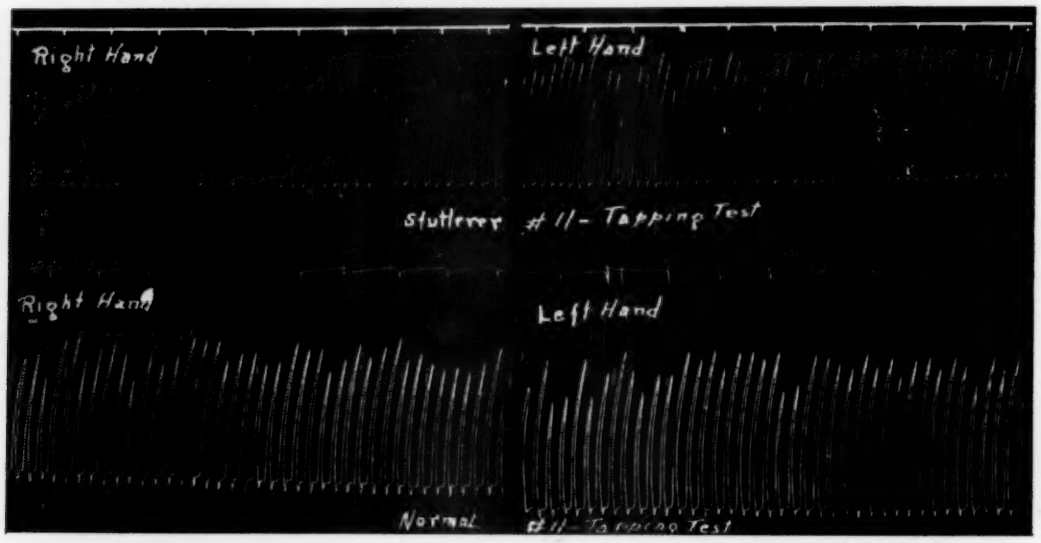

PLATE III

interspersed with coarse contractions. This type of activity was found to characterize the total performance of but one *O*.

VIII. Summary. (1) Stutterers showed a marked inferiority to normal speakers in ability to execute rhythmical, voluntary movements of midline speech structures, in a non-speaking situation. This conclusion applies particularly to voluntary movements of diaphragm and tongue and in a somewhat lesser degree to voluntary movements of lips and jaws. (2) There is no significant difference in the performance of stutterers and normal speakers in voluntary rhythmical movements of structures other than those of speech such as those of arm and hand. (3) Gross qualitative differences exist between the voluntary performances of the speech structures of stutterers and normal speakers, which appear to differentiate several types among the stutterers. (4) From this study it seems that stutterers show a decided inferiority to normal speakers in their ability to control movements of the mid-line speech structures, quite aside from the speech situation.

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A COMPARATIVE STUDY OF AFFECTIVE RESPONSES BY MEANS OF THE IMPRESSIVE AND EXPRESSIVE METHODS [1]

by

DONALD W. DYSINGER

Historical. In the last few decades there has been extensive laboratory research in the field of emotions. In place of the older speculative method, an approach to laboratory procedure was found in the early development of experimental techniques, of which the impressive method was one of the first to be standardized and refined.

This procedure was first employed by *Fechner* in his investigations in the field of æsthetics, the results of which were published in his Vorschule der Æsthetik in 1876 (9). He recognized three particular methods of study. First, the statistical method, by which account was taken of different combinations in actual use, as those found in a certain number of drawing rooms. Second, the method of production, in which the more pleasing impression was produced by the subject, as in drawing. Third, the method of choice, which involved the selection of the most pleasing impression by the observer.

Wundt used the method of impression in an experimental study, the aim of which was to determine whether complementary and almost complementary colors were more or less pleasing than uncomplementary colors. This investigation was made from the standpoint of theoretical æsthetics (11). He later used the same method in a study of affection, from which he concluded that "the analysis of sensations and of the psychical compounds derived from them makes direct use of the impressive method;

[1] This study completed under the supervision of Dr. Christian A. Ruckmick.

while the investigation of simple feelings and the processes resulting from their combination can employ this method only indirectly" (42).

Külpe (15) contributed to the methodology of the affective life by recognizing two general methods of study, (a) the serial method, which involved the systematic application of the stimulus series, and (b) the expressive method, which involved the measurement of the "centrifugal manifestations of feeling." He maintained that the third method suggested by *Fechner* was the only one which lent itself readily to experimental conditions. The other two might be used to supplement it.

Major (17) carried out an investigation to test the serial method as suggested by *Külpe,* and later used by *Witmer* in an experimental study in æsthetics. He used 137 color qualities, which were exposed to the *O*s on backgrounds of black and white respectively. The result of this study was a successful application of the serial method, in a slightly modified form, to the affective tone of colors. In 1894, *Cohn* used the impressive method to study the effect of exposing the colors singly and in pairs to the *O*s in a dark room. Fifteen gelatine films of various colors were used, and the *O*s gave their judgments in terms of agreeableness or disagreeableness.

H. B. MacDougall (2), at the University of Toronto, used the method of impression to study the affective tone of colors. He used 24 colors, each mounted on a cardboard background. The conclusions of this study indicated that, (a) individuals differ in their judgments of agreeableness and disagreeableness of colors, and (b) the judgments of the same individual at different times does not vary to any great extent.

Baker (2) later continued this study using the same 24 colors. Her conclusions confirmed the view that the most pleasing combinations of colors were not those which were complementary, but those between which there is less difference in quality. At about the same time *Dobbie* (6) was carrying out an investigation in the public schools in which 6 colors were used. The pupils were asked to arrange these colors in the order

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most pleasing to them. Though using a different technique, his conclusions confirmed those of *Baker*. He found that the proximity of similar colors is preferred to that of complementary colors, and to that of colors of medium interval.

But in spite of these studies, *Titchener* (31) in 1908, stated that the impressive method was still in its infancy. He mentioned the use of the serial method in two forms, the method of paired comparison and the stimulus method. At the same time he took occasion to defend the method against criticisms which had been made during the preceding few years. Thereupon the procedure seemed to become more generally used. *Potter, Tuttle,* and *Washburn* (20) in 1914 investigated the speed of affective judgment. They devised a scale of five levels, very pleasant, pleasant, indifferent, unpleasant, and very unpleasant, upon which the judgments of the *O*s would be indicated. In 1917 *Geissler* (11) tried to discover whether "the affective tones of two (or more) constituents, when experienced singly, summate when experienced in combination, or do they average, or do they neutralize, or what happens to them?" He concluded that "the unpleasantness of the color pairs increases directly with the pleasantness of the colors taken individually."

More recently *Young* (44) investigated pursuit and avoidance reactions as expressions of pleasantness and unpleasantness. He found that unpleasantness is associated with bodily responses of avoidance, but that the responses accompanying pleasantness were very slight. *Corwin* (4) took exception to these findings on the basis that the technique used had been faulty. After eliminating the objectionable features, she performed a similar experiment in which she found very definite bodily reactions accompanying pleasantness. This controversy remains unsettled due to the seemingly contradictory results secured from their further investigations. The impressive method has been widely used in laboratory experimentation since its introduction into the field. It has placed many of the problems of the affective life, such as the combination of feelings or 'mixed' feelings, relative pleasantness or unpleasantness of combinations of complementary

and uncomplementary colors, and others, within the reach of laboratory treatment.

Galen's observation, during the treatment of a patient, that there was a change of the pulse-rate when the names of certain individuals were mentioned, was the initial step in the development of the methodology for expressive studies of the affective life. This development was very slow, however, many centuries elapsing before systematic laboratory studies were undertaken. *Mosso,* an Italian physiologist, was among the first to carry out such an investigation. His book " La Paura," published in 1889, included the results of this study and was the standard treatise on fear for many years.

The presence of electrical phenomena in the body was known over a century before the galvanic (or psychogalvanic) reflex was discovered. In 1786 *Bertholen* had already published a two volume treatise entitled " L'electricite du humain corps." In 1880, however, *A. D. Waller* noticed some irregular galvanometric deflections in the course of his investigations on the electrotonic changes of excitability of the motor and sensory nerves of man. He attributed these to irregularities in the contact between the skin and the electrodes.

But *Férè* in 1888 was the first to point out that electrical changes occurred in the body during an emotional state. This discovery was made while studying the resistance of the body to a weak electric current. His explanation of the phenomenon was that it was due to a lowering of the resistance of the body during emotional excitation. He reported that such changes were practically insignificant in the case of normal individuals and established on a working basis only in hysterical patients (23).

In the same year *Tarchanoff* worked with the electromotive force of the body and showed that it was a perfectly normal reaction and that it occurred in all healthy individuals. He pointed out that this reaction was concomitant with different types of nervous activity in connection with which a secretory activity was produced (23).

The history of the development of the technique related to the galvanic reflex has been reviewed by both *Prideaux* (23) and

Landis and *DeWick* (16). Notwithstanding previous experimentation, however, the cause of the reflex is, as yet, not definitely known. There are at present two theories regarding its cause: (a) that the deflections are caused by changes in the resistance of the cells of the skin, and (b) that the deflections are due to a counter e.m.f. caused by polarization. The acceptance of one or the other of these theories, or the development of a more satisfactory one, will depend on further investigations.

Statement of Problem. We thus find that while there are still some issues to be settled, the measurement of the psychogalvanic reflex and the impressive method have yielded pertinent results in the investigations of emotion and affection. The tentative validity of each has been established and positive conclusions have been reached. On the basis of the fact that they are valid when used independently, the question has been raised as to the relationship which would be shown when both are used simultaneously in the same affective experience. *Prideaux* (23) states that "any stimulus giving rise to an emotion . . . will, after a certain latent period, cause a deflection which is proportional to the subjective state aroused." *Wechsler* (37) states that "psychogalvanic response appears to vary roughly as the intensity of the affective tone elicited." The present study was undertaken to determine what relationship, if any, exists between the results reached by the use of each one of the two independently used procedures.

For the measurement of the psychogalvanic reflex the Hathaway apparatus (described on the following pages) was used. For recording the impressive judgments of the *O*s, a slightly modified form of the classical impressive method was used. A scale of five points was used varying from the very pleasant at one extreme to very unpleasant at the other. Thus, when a stimulus was presented to *O*, not only was the deflection of the milliameter recorded, but also the subjective judgment as to the affective tone of the object or situation which was being verbally described. Through simultaneous application the two methods were placed on a readily comparable basis.

If the statements of *Prideaux* and *Wechsler* are true, then the

deflections secured from the words judged by *O* to be either very pleasant or very unpleasant should be larger than those secured from words judged to be either indifferent or merely pleasant or unpleasant. If no consistent degree of relationship is found to be present, the validity of one or both of the methods may well be questioned. If, however, a rather consistent relationship is found to be present, the validity of both methods is indicated in proportion to the degree of relationship so determined.

Apparatus. The instrument used in this experiment was the Hathaway Psychogalvanic Response Apparatus.[2]

It uses the 110 v. alternating current secured from an ordinary light socket. This current is held constant by means of two ballast tubes connected in parallel. The 110 v. current is stepped down to 30 v. through a transformer. In this primary circuit are the potentiometer, with a variable resistance of a maximum of 400 ohms, and the electrodes, contact between which is maintained through that part of the body to which they are connected, in this case the palm of the left hand.

A secondary circuit is set up through another transformer. The ammeter, as indicated on the diagram, registers the constant current passing through the circuit. The vacuum tubes, each containing a filament, grid, and plate, are for the purpose of amplifying the minor fluctuations in the current. Battery B_1 produces a potential on the plate of the vacuum tubes. Battery B_2, which together with a resistance, variable from 1,000 to 25,000 ohms, is shunted around the milliammeter, supplies a steady current through the latter. Battery C is applied to produce a difference in potential between the filaments and plates of the vacuum tubes.

A change in the resistance between the electrodes will affect the current passing through the primary circuit, which in turn proportionally changes the current passing through the secondary circuit. Such a change will affect the ionization of the grid, which alters the current passing through the milliammeter. A decrease in the resistance between the electrodes will thus cause an increase in the current passing through the primary circuit, which increases the current passing through the secondary. This increase over and above the constant current passing through the secondary is registered on the milliammeter by deflections of the pointer, in this case to the right. These deflections, resulting from changes in the resistance of the hand, were recorded subsequently to the exposure of each stimulus word.

The electrodes used were round, zinc discs 3.5 cm. in diameter, placed 12 mm. apart. They were attached to a strip of heavy cloth. When attached to the hand of *O*, the electrodes were placed flat against the palm of the hand and the cloth wrapped

[2] The diagram showing electrical connections and parts, together with a full description of the apparatus, has been published since this paper was written, *v.* Hathaway, S. R.. A Comparative study of psychogalvanic and association time measures, *J. Appl. Psychol.*, 13, 1929, 632–646.

around the hand. Under the outer layer of this wrapping a cloth pad was placed to maintain as constant an area of contact as possible. The wrapping was fastened by means of a wire clamp, the ends of which were placed parallel to the palmar and dorsal surfaces of the hand.[3] After attaching the electrodes in this manner *E* questioned *O* to make sure that the wrapping was not tight enough to cause discomfort. Special care was exercised in this regard to avoid interfering with the normal circulation through the hand, which would invalidate the reading secured. The time elapsing between the attachment of the electrodes and taking the readings allowed for the attainment of a maximum of humidity from perspiration, thus maintaining a constancy of contact during the readings.

Words were printed by hand on cards, 13.9 cm. by 10 cm. to serve as stimuli. The lettering was 7 mm. in height, spaced so that the *O*s would encounter no difficulty in reading the words at the distance at which the cards were placed, approximately 1 meter.

The cards were illuminated by means of a 75 watt Mazda globe, placed in an ordinary table lamp. The light was kept at a constant distance from the stimulus cards, namely 32 cm. The light was adjusted so that there would be no glare on the cards which might interfere with *O*'s view of the printed word.

In order to reduce movement on the part of *O* as much as possible, the affective responses to the stimulus words were indicated by pointing to the proper symbol on a chart made for the purpose. The chart was printed by hand in black ink, on manilla cardboard, and was 20 cm. by 9 cm. in size. The printing was 1.3 cm. in height for the small letters and 2.5 cm. for the capital letters. The symbols used on the reference chart were, a capital P for "very pleasant," a small p for "pleasant," o for "indifferent," a small u for "unpleasant," and a capital U for "very unpleasant." These symbols were placed 3.5 cm. apart on the chart and their order, reading from the left to the right of *O* was

[3] An improved type of electrode has since been devised by Dr. Christian A. Ruckmick, which was described in an article entitled, "A new electrode for the Hathaway Apparatus," in the *Amer. J. Psychol.*, 42, 1930, 106–107.

P, p, o, u, U. The meaning of these symbols was given to the *O*s in their instructions provided in typewritten form, as follows:

Words will be presented to you on cards. Use the pointer to point to the symbol on the chart which indicates its effect on you:

u for every word which indicates any object or situation which is unpleasant.
U for every word which indicates any object or situation which is VERY unpleasant.
p for every word which indicates any object or situation which is pleasant.
P for every word which indicates any object or situation which is VERY pleasant.
o for every word which indicates any object or situation which is indifferent.

Judge according to the feeling response which IMMEDIATELY associates itself with the meaning of the word to you. This is very important.
Each word is to be responded to.

The pointer used was a light wooden one, 38.5 cm. in length. The forearm of *O* was rested on the table, with the pointer held in the right hand and the chart placed about 2 to 3 cm. beyond its tip. *E* demonstrated to each *O* the most satisfactory way to use the pointer, in which the necessary movements from side to side might be made by simple movements of the thumb and index finger.

The three series of words used as stimuli in the experiment were as follows:

SERIES A

1. trip
2. street
3. pus
4. calender
5. desire
6. soul
7. sticky
8. lunatic
9. desk
10. birth
11. worship
12. cocktail
13. bulb
14. thrill
15. whiskers
16. day dream
17. virgin
18. wash
19. broom
20. poison
21. caress
22. typewriter
23. blood
24. door
25. stork
26. heaven
27. smoke
28. clap
29. rug
30. modesty
31. cotton
32. floor
33. comma
34. unwell
35. hat
36. snow
37. virtue
38. fruit
39. pleasure
40. chamber
41. onion
42. syringe
43. kick
44. hot
45. suspicion
46. spree
47. ink
48. pet
49. grate
50. tease

SERIES B

1. chair
2. undress
3. basket
4. suicide
5. song
6. baby
7. ghost
8. gift
9. naked
10. brush
11. derby
12. rubber
13. divine
14. pipe
15. darling
16. hungry
17. fun
18. slop
19. cool
20. failure
21. wound
22. vacation
23. event
24. blush
25. theater
26. space
27. jazz
28. string
29. hell
30. elect
31. folder
32. corpse
33. paper
34. sky
35. jealous
36. mosquito
37. comedian
38. pregnant
39. cloth
40. bell
41. god
42. leak
43. key
44. preventative
45. mule
46. queer
47. yellow
48. tickle
49. gutter
50. letter

SERIES C

1. wax
2. picture
3. honeymoon
4. bread
5. dance
6. book
7. candy
8. kiss
9. sleep
10. red
11. slimy
12. bed
13. safety
14. worry
15. sleigh-ride
16. jail
17. mother
18. travel
19. funeral
20. dream
21. stink
22. money
23. habit
24. syphilitic
25. dog
26. name
27. flower
28. love
29. shirt
30. stove
31. sexual intercourse
32. music
33. proud
34. make
35. vomit
36. step
37. mistress
38. hand
39. sheet
40. afraid
41. divorce
42. dam
43. breast
44. ship
45. rich
46. excretion
47. speak
48. canoe
49. marry
50. church

The *Pressey* Cross-Out Test, the *Kent-Rosanoff* Free Association Test, the investigation by *W. W. Smith* (29), and a list of

words used by Dr. *O. H. Lundholm* in an unpublished study of the emotions, were the sources used by *E* in the selection of stimulus words. The words chosen from these tests were augmented by others selected by *E* as being suitable for the purpose.

Words from which we anticipated the more extreme responses were separated by words likely to be neutral in tone.

Procedure. The procedure followed for each sitting was as follows: *O* was taken into a small room and seated at a table at right angles to its longer dimension. The chair in which he was seated was one similar to those used in the lecture room with the writing surface on the left side. *E* handed him the typewritten instructions and while these were being read, the instrument was opened, the cards adjusted in the rack prepared for the purpose, the light given the proper adjustment, and the chart placed in position. After *O* had read the instructions, *E* demonstrated the method suggested for pointing and handed the pointer to *O*. The electrodes were next attached to *O*'s left hand. At this point the suggestion was made that during the experiment *O* lay his left hand, palm down, on the writing surface of the chair in as comfortable a position as possible. The Hathaway apparatus was then adjusted for the reading, and the potentiometer setting recorded. The stimulus words were then exposed to *O* at intervals of about fifteen seconds.

During the course of each sitting *E* watched carefully for movements of *O*, especially swallowing, and no readings were recorded when these were observed to interfere with the deflection resulting from the exposure of the stimulus word. While each word was exposed, *E* recorded the affective response of *O*, as indicated on the chart, as well as the deflections of the milliammeter and its direction. Following this plan a reading was taken for each of the stimulus words in the series.

Observers. There were thirteen *O*s used during the course of this experiment. Of these, six were graduate students in psychology (A, B, C, D, E, and F), four were taking undergraduate work in the department (G, H, I, and J), and three had taken

no courses in psychology at all (K, L, and M). Three observations were secured from all of these except J, from whom only one sitting was taken.

The series of stimulus words were given to all the *O*s in the same order, namely, A first, B second, and C last. With a few exceptions, each *O* was taken at about the same time of day for all three series. This, however, was not essential for the purpose of the investigation, as the comparisons to be made were only within each individual series. No *O* observed more than once in a single day. Further than this, no effort was made to keep the interval between the observations of the various *O*s constant.

SERIES A

	Very Pleasant		Pleasant		Indifferent		Unpleasant		Very Unpleasant	
O	A.M.	S.D.	A.M.	S.D.	A.M.	S.D.	A.M.	S.D.	A.M.	S.D.
A	.110	.050	.102	.035	.080	.037	.123	.047	.060	0
B	.107	.027	.070	.031	.055	.040	.065	.031	.103	.029
C	.113	.009	.082	.020	.059	.025	.097	.036	.120	.020
D			.073	.013	.054	.019	.068	.023		
E					.059	.024				
F			.110	.037	.083	.028	.131	.056	.100	0
G	.190	.067	.122	.108	.065	.034	.112	.044	.210	.050
H			.063	.021	.056	.026	.070	.010		
I	.144	.067	.091	.045	.081	.027	.107	.042	.153	.055
J	.040	0	.095	.047	.056	.028	.053	.009		
K	.065	.022	.086	.060	.053	.034	.056	.030	.080	.020
L	.033	.015	.026	.014	.027	.015	.038	.015	.030	.010
M	.080	0	.073	.017	.067	.034	.066	.023	.100	.016

This table indicates the relationship between the deflections of the milliammeter and the affective responses. The *O*s are indicated in the extreme left-hand column. 'A.M.' is the arithmetical mean of the deflections resulting from the exposure of all the stimulus words given the particular affective response which is at the head of the column. Means are given for all five types of affective response for each *O*. 'S.D.' is the standard deviation of the deflections from which each mean is calculated. The five types of affective responses are indicated in the headings of each column.

SERIES B

	Very Pleasant		Pleasant		Indifferent		Unpleasant		Very Unpleasant	
O	A.M.	S.D.	A.M.	S.D.	A.M.	S.D.	A.M.	S.D.	A.M.	S.D.
A	.160	0	.134	.070	.094	.057	.120	.038	.220	0
B	.104	.043	.075	.030	.075	.029	.090	.030	.108	.041
C	.116	.029	.095	.021	.067	.015	.108	.024	.124	.019
D			.089	.026	.070	.021	.107	.046		
E			.083	.025	.057	.019	.090	.010		
F			.113	.029	.081	.031	.124	.048	.190	.030
G	.148	.035	.163	.059	.134	.069	.162	.062	.340	.040
H			.095	.046	.075	.027	.109	.035		
I	.100	.060	.108	.042	.102	.049	.130	.049	.167	.081
K	.107	.038	.087	.035	.070	.035	.083	.031	.080	.028
L	.144	.062	.112	.051	.094	.045	.116	.043	.147	.099
M	.120		.068	.017	.035	.013	.066	.013	.127	.024

SERIES C

	Very Pleasant		Pleasant		Indifferent		Unpleasant		Very Unpleasant	
O	A.M.	S.D.	A.M.	S.D.	A.M.	S.D.	A.M.	S.D.	A.M.	S.D.
A	.148	.020	.100	.036	.086	.035	.108	.026	.140	.010
B	.160	.061	.123	.069	.074	.043	.129	.038	.180	0
C	.100	0	.085	.027	.060	.016	.088	.020	.117	.021
D			.135	.048	.092	.034	.117	.021		
E			.065	.015	.043	.011				
F	.180	.040	.119	.036	.088	.037	.126	.036	.200	.043
G	.120	0	.155	.060	.215	.103	.174	.098	.260	.100
H	.090	.010	.056	.026	.037	.012	.071	.037		
I	.220	0	.065	.020	.057	.028	.067	.015	.130	.050
K	.135	.024	.078	.026	.045	.013	.067	.023	.127	.025
L	.160	.077	.121	.059	.066	.015	.120	.037	.184	.107
M	.160	0	.102	.026	.118	.066	.110	.032	.177	.050

Discussion. An examination of Table I will show that in 25 out of the 37 cases, or 67.5%, the magnitude of the deflections resulting from an exposure of a stimulus word is indicative of the degree of affective tone reported by *O*. Thus words, to which affective responses of " very pleasant " or " very unpleasant " were elicited, resulted in a larger deflection than those words to which *O* responded as merely " pleasant " or " unpleasant," and the magnitude of the deflections resulting from the latter were larger than from the words which elicited a response of indifference.

If the magnitude of the deflections is entirely independent of

the affective tone elicited by the stimulus words, the means of Table I might be considered the result of a random grouping of the deflections resulting from the exposure of all the words in the series. In this case the difference between adjacent means would not be statistically significant.

The statistical significance of the difference between these means has been determined by the application of the formula for the Standard Error of a Difference,

$$\text{S.E. Difference} = \sqrt{\text{S.D.}^2_{\text{(av. 1)}} + \text{S.D.}^2_{\text{(av. 2)}}}.$$

This result may be interpreted in terms of chances in 100 by means of a table given by *Garrett* (10). The average of these chances in 100 that the difference is significant was found to be 89.6 for the three series. Since this average is 89.6 for all pairs of adjacent means, it is reasonable to assume that a true difference does exist. The relative consistency of the relationship between the affective responses of the *O*s and the magnitude of the deflections leads to the conclusion that some common factor underlies both. In the absence of any other proved relationship, it is fair to assume that both are measuring the same thing, namely the affective tone of *O* resulting from stimulation by printed words.

In the consideration of the results, there are several complicating factors which must be taken into account.

In the first place, the objective affective responses of *O* must be made on a scale of five levels, although the subjective scales of pleasantness and unpleasantness are continuous ones. The necessity of reporting the affective responses on a scale limited to two levels for pleasantness and two for unpleasantness involves an undetermined amount of error. This is not only due to the fact that the units of the rating scale are large, but also to the subjective and variable nature of the points of differentiation between them. If the deflections of the milliammeter are dependent upon the affective tone aroused in *O* and such an error is involved, any inconsistency in differentiating between one response and another by *O* will tend toward the reduction of the significance of the differences between adjacent means.

Another factor of importance is the possibility of a change in the affective tone of *O* in the interval during which the readings were being taken. *O* was instructed to report the affective tone which followed immediately upon the exposure of the stimulus word. This would undoubtedly be followed by a train of associations which might or might not maintain the originally reported affective tone. The latter would be the result of an image or idea of the stimulus word or the object or situation of which it was a symbol. The change might come about through the recall of past experiences of an entirely different affective tone. Thus a word which elicited a response of "indifferent" might later recall an experience which was "pleasant" or "unpleasant" in almost any degree. Two *O*s, after the completion of their observations, volunteered the information that the affective tone as first reported was not always constant during the interval before the next word was exposed. Each remarked that the recall of past experience served to alter their affective tone from that first reported to a different one. The affective response and the deflection of the milliammeter were not coterminous. The time allowed for the latter would necessarily include the latent period and the deflection of the pointer, while the former was an immediate response. The effect of such alterations of affective tone could not easily be checked in this investigation.

In the present study no attempt was made to control the mental processes of *O* in the interval during which the readings were being taken. The only way that errors of the type described in the previous paragraph could be avoided would be to have control of this period. This could be accomplished by supplying *O* with a task to perform. This would have to be easy enough to avoid the possibility of failure and sufficiently difficult to require the constant attention of *O*.

The constant reliability of the affective responses of the *O*s was assumed in this study. Especially in the cases of the untrained *O*s this might be questioned. Any change in the position of the point of differentiation between adjacent responses, such as "indifferent" and "pleasant" or "unpleasant" and "very

unpleasant," would involve some degree of variation from the results which would have been obtained otherwise. Such a change would have a tendency to render less significant any difference between the two groups directly involved. This is a criticism of the impressive method in general, however, and not of the particular application of it used in this study.

An examination of the 12 cases listed as those in which the magnitude of deflection does not correspond to the degree of affective tone reported by *O* is of interest. In one of these an indifferent response was given to every word in the series. In seven of the remaining 11 cases the mean deflection for the words given one type of response appears to be out of the proportion necessary for such correspondence. This could also be interpreted to mean that the four averages were out of proportion and the single item correct. This question involves the acceptance of four items out of five as indicative of the tendency of the entire group or of one item of five as indicative. The mere weight of numbers tends toward the acceptance of the former alternative.

In the remaining four cases the lack of correspondence was more general. In two of these the tendency was toward an inverse relationship between the magnitude of deflection and the affective response. In the remaining two the means were so scattered that no general statement can be made regarding them in reference to their correspondence.

Although several complicating factors have been mentioned which might be sources of error, due to the fact that they were uncontrolled during the period of experimentation, they do not clearly explain the lack of correspondence between the magnitude of deflection and the affective response of *O*s in the 12 cases cited. The acceptance of one group in preference to the other as a basis for general conclusions can only be made because of numerical predominance. For this reason the 25 cases, in which there was a complete correspondence between the magnitude of deflection and the affective response, are taken in preference to those 12 in which such correspondence is either

incomplete or lacking. It is possible that when these complicating factors exert their influence to a minimal degree a correspondence between the magnitude of deflection and the degree of affective tone reported by *O* is present. But when these factors work at maximum, such correspondence is lacking. This can be determined accurately only by bringing these factors under control and observing the correspondence which would then be present.

It may be concluded from this study that the magnitude of the deflection of the milliammeter is roughly indicative of the affective response of *O* as elicited by stimulus words. The uncontrolled mental content of *O* in the interval between the exposure of successive stimulus words, and the unreliability of *O*'s objective report of his affective tone are factors which possibly serve to decrease the degree of correspondence so found.

Series of words to be used for this purpose should include a larger number of words which bring consistent responses of " very pleasant " or " very unpleasant." By increasing the number of these extreme judgments secured, a more accurate, and possibly a more consistent, correspondence between the affective responses and milliammeter deflections could be secured.

Conclusions. 1. There is a striking correspondence between the affective tone reported by *O* and the magnitude of the milliammeter deflections in the great majority of cases.

2. In most of the remaining cases there is evidence of such a correspondence, although incomplete.

3. In a very few cases such a correspondence was entirely lacking.

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AN INVESTIGATION OF THE PHENOMENA CONNECTED WITH THE BEATING COMPLEX[1]

BY

INGVALD B. HAUGE

Survey of previous investigations. This study finds its origin in two diverse situations: (1) there are at present several significant aspects of the beating complex that are still unsolved, and (2) a number of conflicting results have appeared in the studies of previous investigators of this subject.

A survey of the literature reveals in the first place no exact definition of the concept of the beating complex. The term is used to designate the auditory experience associated with the simultaneous sounding of two tones of different pitches; no one has defined the limit of the difference in pitch of the tones for any one region of the tonal scale, but there is agreement to the effect that the term does not apply when the difference in pitch of the two tones becomes large enough to give rise to the experience of smoothness and blending involved in consonance.

When primaries of 256 and 264 ~ are sounded together, *Myers* (**14**, pp. 37–38) finds that the beating arises from the varying intensity of a single tone whose pitch is closer to that of the lower primary. As the difference in frequency is increased the higher primary becomes distinguishable before the lower primary does, but the intertone carries the beat. It has a softer character than the primary tones. *Myers,* however, is not specific when we consider the intensive relations of the primaries. Similar results are reported by *Titchener* (**24**, p. 105), who writes that with a slight difference in the pitch of the primaries a single

[1] I wish to express acknowledgments to Professor Christian A. Ruckmick, under whose direction this study was made; to Dean Carl E. Seashore for many helpful suggestions; and to the observers who gave so freely of their time.

tone fluctuating in intensity is heard whose pitch is indistinguishable from that of the primaries. As the difference in the frequencies of the primaries is increased, the pitch of the single beating tone which is near that of the lower primary at first rises until it approaches the pitch of the higher primary. With the primaries at 256 and 288 ~ the primary tones are heard concomitantly with the beating intertone; the upper primary appears as a smooth and continuous tone; the lower primary is heard less easily than the upper and seems to have no share in the production of beats. *Titchener* fails, however, to note the intensive relations of the primaries and the difference in frequency at which the pitch of the intertone comes closer to the pitch of the upper than to that of the lower primary.

According to *Stumpf* (19) only one tone, which is beating, is heard when the difference in the frequencies of the primaries is less than 20 ~ with the upper primary at 440 ~. When the difference is increased to 22 ~, both primary tones are heard in addition to the beating intertone whose pitch is intermediate between that of the primaries. With a difference of 44 ~ only the two primary tones are heard and these seem to beat; whichever one is attended to seems to be the beating tone. More recently *Stumpf* (20) states that we must expect to hear the pitch of the intertone as situated between that of the two primaries. Providing the primaries are of equal strength, it lies about or exactly in the center; but in the case of unequal strength, it leans towards the stronger primary in pitch. *Meyer* (12) agrees with *Stumpf* in regard to the pitch of the intertone. For *Bosanquet* (3) the critical interval at which the two primary tones begin to be heard in addition to the beating intertone is about 12.8 ~ when the lower primary is at 512 ~. As the interval is increased, the primary tones become more and more prominent and the beating tone diminishes in loudness and distinctness until it disappears with a difference in frequencies of 102.4 ~. *Bosanquet* fails to note whether the pitch of the intertone remains midway between the primaries as the difference in frequencies is increased and is not specific as to the intensive rela-

tions of the primaries. *Kreuger* (10) finds that, without exception, the pitch of the intertone heard lies closer to the pitch of the lower primary tone. As the difference in frequencies is increased to 34 ~ with the lower primary at 512 ~, the pitch of the intertone rises slowly but remains nearer the lower primary in pitch.

In a recent investigation of the beating complex *Eberhardt* (5) finds that only one tone of constant pitch is heard when the difference in the frequencies of the primaries is less than 8 ~ and when the lower primary has a frequency of 660 ~. With the primaries at equal intensities the pitch of the beating intertone lies approximately midway between them, but with unequal intensities it lies closer to the louder primary in pitch. When the differences in the frequencies range from 8 to 15 ~, only one tone is heard so long as one primary is much more intense than the other. When the intensive difference is less, two tones are heard in the majority of cases; the pitch of one is from 2 to 5 ~ away from the first and between the primaries depending on the differences in intensity and frequency of the primary tones. This investigator reports that there are considerable individual differences in the ability to hear two tones in the above situation. When the primaries are equal in intensity, two tones are heard whose pitches are between the primaries and equally far from the center. As the difference in the frequencies of the primaries is increased, the pitches of the intertones move farther away from the center until finally the primary tones themselves are heard. *Eberhardt* fails to mention at what difference in the frequencies the primary tones begin to be heard. With the primary tones at 256 and 244 ~ similar results were obtained by the present writer (8).

In a theoretical discussion of the conditions under which variations of pitch in beats occur *Taylor* (22) states that when the higher of the two tones of nearly the same pitch is the more intense, the pitch of the resultant tone will lie between the two primaries when the two sets of waves are in complete accordance and the intensity of the resultant tone therefore of maximal degree and that the pitch of the resultant tone will be higher than

the pitch of the higher primary when the intensity of the resultant tone is of minimal degree. When the lower of the two tones is the more intense, the pitch of the resultant tone will lie between that of the two primaries whenever the resultant is at maximal intensity; whenever the resultant is at minimal intensity, its pitch will be lower than the pitch of the lower primary. With both primaries at equal intensities there will be no variation in the pitch of the resultant. *Taylor* (22, pp. 62–63) reports some empirical observations which are in accord with his theoretical conclusions. *Helmholtz* (9, pp. 165, 415), like *Taylor*, describes the effect as an intensive fluctuation with slight oscillations in pitch on the part of the beating sound. *De Morgan* (13, p. 137) speaks of the existence of alterations of pitch in beats as a known fact which he has verified experimentally.

Stumpf (20, p. 478), however, hears in slow beats only one tone constant in pitch. *Terquem and Bossinesq* (23) find that the pitch during the maximal intensity of the beat corresponds to the calculated pitch but that during the minimal intensity of the beat the pitch cannot be determined by hearing although it can be calculated.

All investigators agree that the beating complex changes in quality as the difference in the frequencies of the primaries is increased, but few adequate qualitative descriptions are given. *Myers* (14, p. 37) recognizes four stages as the frequency of the beats is increased when the lower primary is at 256 ~ and writes, "In the first stage they, the beats, have a surging character, in the second a thrusting, and in the third a rattling character; finally they fuse and pass into a stage where only roughness remains, beyond which they completely disappear." The first, second, third, and fourth states reach their maximals when the lower primary is at 256 ~ and the upper primary is at 264, 272, 284, and 300 ~, respectively. *Wever*[2] (25) observes three stages, noticeable oscillations or surges of intensity, intermittence or pulsation of tone, and roughness without intermittence, but adds that there is considerable overlapping of these stages.

[2] Wever's article was published after the present experimental work was completed.

Problem. The aim of this research was to make a thorough analysis of the beating complex under rigorous conditions of control. In view of the many diverse opinions and data discussed above, we strove to obtain information from observers' reports that would throw some light on these conflicting results, and that would reveal, at the same time, additional facts concerning the phenomenon of the beat. The experiments in Series I were performed to secure descriptions of the beating complex (1) when the primaries were at minimal, medium and maximal intensities, and (2) when the primaries differed mainly in frequency. In Series II the object was to obtain accounts of the beating complex when the relative intensities of the primaries were unequal. The experiments in Series III were conducted to get descriptions of the beating complex when the intensities of both primaries were (1) reduced from maximal to minimal degrees, and (2) increased from minimal to maximal degrees. In Series IV we aimed to secure accounts of the beating complex when the intensity of one primary was increased at the same time as the intensity of the other primary was decreased. The object of the experiments in Series V was to determine if there were pitch variations in the beat. The experiments in Series VI were performed to determine the relation of changes of pitch in the complex to the appearance of beats and those of Series VII were done to determine how many tones were heard in the beating complex at various intensive relations of the primaries and at various differences in frequency. The object of the experiments in Series VIII was to ascertain the effect of changes in the relative intensities of the primaries on the pitch of the dominant, higher and lower tones in the beating complex. In Series IX the purpose was to determine the pitch of the dominant, higher and lower tones in the complex by comparing them with tones of known frequencies when the primaries had various intensive relations and various differences in frequency. The last series of experiments was conducted to get at the effect of changes in the relative intensities and differences in the frequencies of the primaries on the qualitative description of the beating complex.

Technique. An adequate study of the problems involved in this research required a means of producing two comparatively pure tones whose pitches could be increased or decreased independently and whose intensities could be independently varied without affecting the frequency in either case. At first the heterodyning method of producing tones was tried and discarded because the slight but physically unavoidable fluctuation in the two radio-frequencies produced an easily perceived pitch fluctuation in the resultant audio-frequency.

The audio-oscillator method was then developed and used. It was supplemented throughout by the use of electrically driven tuning forks. The latter method made possible the production of pure tones and avoided the use of a telephone receiver. In the last of the ten series of experiments Stern variators were used because they satisfied the particular requirements of this series more completely than the two previous techniques. We required an arrangement for varying the differences in the frequencies of the primaries quickly and a method of producing comparatively pure tones of approximately equal intensity.

The first problem in the use of the audio-oscillators as the source of the two tones was the selection of a method of bringing both tones to one ear. Consideration of various possible means led to the use of a single telephone receiver connected in series with two coils inductively coupled to the respective oscillators. The telephone receiver was placed in a sound-proof room and adjusted to the height of *O*'s ear so that its top part just touched the ear. A device for varying the distances between the inductively coupled coils and their respective oscillators afforded intensive variations in the tones. Changes in frequency were effected by varying the capacity by means of condensers. When tuning forks were used, the tones were conducted to *O*, who was seated in a sound-proof room, through rubber tubes ending in a small horn large enough to cover *O*'s ear. The intensity of each fork was varied by changing the size of the opening of its resonator. Changes in frequency were made by weighting the prongs of the forks. A constant source of air for the Stern variators was

secured by using the centrifugal pump of a vacuum cleaner. *O* was seated with his back toward the source of sound at a distance of one meter. All pitch calibrations were made with the Seashore tonoscope (17).

Eight *O*s, three women and five men, were used. All the *O*s ranked high in the Seashore tests of pitch and intensity (16). Seven of the *O*s were graduate students in psychology; one *O* was doing research work beyond the doctorate in the field of musical talent. Two of the *O*s were experienced musicians. All of the *O*s had had experience in the observation of auditory phenomena, but none had observed in previous experiments on the beating complex. The *O*s were instructed to avoid any discussion of their observations.

The first four series of experiments were conducted for the purpose of securing the *O*s' description of the beating complex in their own terms. In these four series the only instruction given *O* was: "You will be presented with auditory stimuli which you will be asked to describe." The last six series of experiments grew out of the reports secured in the first four series, *i.e.*, the descriptions given by the *O*s showed that phenomena were present which would require different procedures and different instructions for their adequate determination.

The positions of the intensive controls at which the two tones were judged to be of maximal and equal, medium and equal, and minimal and equal intensities were determined for the oscillators and for the tuning forks. In the following pages the numerals 3, 2 and 1 will refer to maximal, medium and minimal intensity, respectively, of any one tone. The relative intensities of the primaries in the complex will be indicated by two numerals separated by a comma, *e.g.*, "3,2." The numeral placed before the comma refers to the intensity of the upper primary; the numeral placed after the comma refers to the intensity of the lower primary. A decrease in intensity from maximal to minimal is indicated by "3–1"; and an increase by "1–3." The numerals placed before the colon refer to the intensive change in the upper primary; the numerals after the colon refer to the intensive change in the lower primary, *e.g.*, "3–1 :1–3."

Series I was performed to secure descriptions of the beating complex when the intensive relations were (1) 3,3, (2) 2,2, and (3) 1,1. When the oscillators were used, the lower primary was held constant at 256 ~, while the differences in the frequencies were ½, 9, 18, 27, 36, 45, and 54 ~. When the tuning forks were used, the upper primary was held constant at 512 ~ while the lower primary was varied in steps of ½, 6, 12, and 24 ~. The order of presenting the stimuli was that of beginning with the smallest difference in frequency and then reversing the order. *O* was permitted to listen to the auditory stimuli for three minutes. The stimulus was cut off for four seconds at the end of each minute and for two seconds at the end of every fifteen seconds during the minute.

In Series II the following intensive relations were used: (1) 3,1, (2) 3,2, (3) 2,3, and (4) 1,3. Tuning forks of the same frequencies as in Series I were used with the exception of the 511.5 and 506 ~ forks. The method of presenting the stimuli was the same as that used in Series I. The stimuli were given according to a chance distribution of the four types of intensive relations.

From Series III of the experiments we secured reports on the beating complex when the intensities of both primaries were (1) 3–1 :3–1 and (2) 1–3 :1–3. Oscillator tones of the same frequencies as in Series I were used. The stimuli lasted for ten seconds.

The purpose of Series IV was to secure descriptions of the beating complex when the intensive changes 3–1 :1–3 and 1–3 :3–1 were used. The duration of each type of intensive change was ten seconds and the two types of intensive changes were given according to a chance distribution.

Series V finds its origin in (1) the *O*s' descriptions to the effect that the pitch varied when the beat was slow, (2) previous investigations (22, 9, p. 415, 13, p. 137), (3) theoretical pitch variations (22), and in (4) the results of photographing two tones of nearly the same frequency.

The phono-photographic apparatus, described by *Metfessel* (11, pp. 4–6) was used in photographing tones coming from two elec-

trically maintained tuning forks having frequencies of 256 and 240 ~. Since the main purpose of photographing was to determine the direction of the changes in the resultant frequency when different intensive relations obtained between the primaries, no exact physical measurements were made of the intensity of the tones. The results of photographing show that at the points of maximum amplitude the resultant frequency will always lie between the frequencies of the primaries. At the points of minimum amplitude the resultant will pass beyond the limits of (1) the frequency of the upper primary when that is more intense than the lower, and (2) the frequency of the lower primary when it is more intense than the upper. Furthermore, the greater the intensive difference of the primaries, the smaller are the changes in the resultant frequency and the more nearly does the resultant frequency approach the frequency of the more intense primary. The above statements agree with *Taylor's* (22) calculations. The results of photographing and plotting the resultant of two sine curves show in addition that, as the difference in the amplitudes of the primaries becomes less, the resultant frequency (1) remains within the limits of the primary frequencies for a longer period of time, and (2) becomes more nearly constant during that time.

The purpose of Series V of the experiments was to determine the presence and the direction of pitch changes in the beating tone (1) when the upper is sounding more intensely than the lower primary, (2) when the upper primary is sounding less intensely than the lower and (3) when both primaries are equal in intensity. A short series of observations showed that one beat per second was sufficiently slow to permit a comparison of the pitch of the most intense portion with the least intense portion of the tone. Two sets of primary tones were selected having frequencies of 256 and 255 ~ and 512 and 511 ~. In this series tuning forks were used. The following four types of presentation were given according to a chance distribution: (1) the upper was sounding at maximal and the lower at medium intensity; (2) both primaries were sounding at equal and medium intensities; (3) the upper primary was sounding at medium and the lower at maximal, and

(4) the upper primary was reduced in intensity from maximal to minimal once every second. The instructions given *O* were: "Observe if there are any pitch changes in the auditory stimuli; if there are any, note whether the intense portion of the sound is lower, higher, or the same in pitch as the less intense portion. You will be permitted to observe for 60 seconds." The above procedure was followed by a short series of observations in which the upper primary tone was given to *O* at maximal intensity for two seconds followed or preceded, according to a chance distribution, by the same tone at minimal intensity. The instructions were: "You will hear two tones. You are to judge if the second tone is higher, lower, or the same in pitch as the first."

The reports secured in Series IV revealed problems which required different instructions and procedures. The problems were to determine (1) if the beats appear before a lower pitched tone is perceived when the intensity of the upper primary is decreased as the intensity of the lower is increased, and (2) if the beats appear before a higher pitched tone is perceived when the intensity of the upper primary is increased as the intensity of the lower is decreased. It was the purpose of Series VI to answer the above questions. Four types of trials were used. In the first the intensity of the upper primary was decreased from a point above maximal while the lower primary was increased from a point below minimal intensity. The instructions were: "Signal when the beating begins and when it disappears." In the second the intensive change on the part of each tone was the opposite of that used in the first series. The instructions were the same as those given in the first series. In the third and fourth series the procedures of the first and the second series, respectively, were used. In the third series *O* was instructed to "Signal when a lower pitched tone appears" and in the fourth series to "Signal when a higher pitched tone appears." The two oscillator tones used were at 256 and 263 ~, respectively. The rate at which the intensities were changed was varied in a random manner by means of the intensive controls, but the change always occupied more than 20 seconds. *O* signalled *E* by means of a mercury contact key which operated a light in the experimenter's room.

The object of the experiments in Series VII was to determine how many pitches are heard in the beating complex when the upper primary is held constant at a frequency of 512 ~ and when the differences in frequency are 6, 12, and 24 ~. The following five intensive relations obtained between the primaries: (1) 3,1, (2) 3,2, (3) 2,2, (4) 2,3, and (5) 1,3. These five types were given according to a chance distribution with the instructions, "You will hear a beating complex. Analyze your auditory experience in order to determine if you hear just one pitch. If you hear more than one, note how many you hear. You will be permitted to listen for two minutes."

The procedures and instructions in Series VIII were drawn up on the basis of the reports secured in the previous series. The previous reports showed that with certain intensive relations and differences in frequency one dominant pitch is heard when there is no attempt at analysis and that a higher and a lower pitch is heard when *O* attempts to analyze his auditory experience. Consequently the object of Series VIII was to determine if the dominant, the higher and the lower pitches change when the relative intensities of the primaries are altered. The difference in the frequency of the forks was 24 ~ with the upper constant at 512 ~. Each of the five intensive relationships used in Series VII was compared with every other under the following types of instructions: (1) "Attend to the dominant pitch of the beating complex. If the dominant pitch becomes lower, report lower; if it becomes higher, report higher; if it does not change, report 'same.'" (2) "Attend to the highest pitched component in the beating complex. If it does not disappear, report 'same'; if it disappears, note whether the succeeding highest pitched component is lower or higher in pitch. If the second is higher, report higher; if it is lower, report lower." (3) "Attend to the lowest pitched component in the beating complex. If it does not disappear, report 'same.' If it disappears, note whether the succeeding lowest pitched component is lower or higher in pitch. If the second is higher, report higher; if it is lower, report lower." When instruction number one was given, each intensive relationship was given for three seconds with no interval of time between

the two. With instruction number two and number three the first intensive relationship was given for ten seconds and the second for five seconds with no interval of time between the two.

The experiments in Series IX were performed to determine the pitch of the dominant, the higher and the lower tones in the beating complex by comparing these with a tone of known pitch. When each of the five intensive relationships, explained in Series VII, obtained and when the primary tones were at 512 and 488 ~, these three tones were compared in pitch with tones of 488, 494, 500, 506 and 512 ~, respectively. When the primaries had frequencies of 512 and 500 ~, the comparison tone had a frequency of 506 ~. A comparison tone of 509 ~ was used when the primaries were at 512 and 506 ~. The beating complex was presented first and was followed by the comparison tone after an interval of about one second. These three types of instructions were given according to a chance distribution: (1) "Attend to the dominant pitch of the beating complex. You are to judge if the pitch of the second tone, which you will hear after an interval of one second, is higher, lower, or the same. You will be asked to report." (2) "Attend to the highest pitch in the beating complex. You are to judge if the pitch of the second tone, which you will hear after an interval of one second, is higher, lower, or the same. You will be asked to report." (3) "Attend to the lowest pitch in the complex. You are to judge if the pitch of the second tone, which you will hear after an interval of one second, is higher, lower or the same. You will be asked to report." The five types of intensive relationships were given according to a chance distribution. Instructions number two and number three were not given when the primaries were at 512 and 506 ~.

The experiments in Part I of Series X were performed to determine how the beating complex changed when the intensive relations of the primaries were altered. The frequency of the upper fork was 512 ~, while that of the lower was 488 ~. The intensive relations, 3,1, 2,2, 1,3, were compared with each other in a random manner; the intensive relations, 2,2 and 3,3, were also compared with each other with the following instructions to

O: "Attend to the beating effect and observe whether it changes in any way outside of pitch; you will be asked to describe your experience."

Differences of 8, 16, 28 and 44 ~ in the frequencies of the primaries were used in the procedure of Part II of Series X. *O* was permitted to compare the beating complex of one difference in frequency with the beating complex of each of the other differences in frequencies. Each of the two beating complexes which were to be compared were given for eight seconds with an intervening interval of two seconds. The lower primary was constant at 256 ~ and approximately equal in intensity to the upper. The instructions were: "Attend to the character of the beating complex and observe how it differs in the second part of the presentation. Pay no attention to changes in pitch. You will be asked to describe it in your own terms." The sources of the tones were two Stern variators.

Apparatus. The audio-oscillator apparatus, Figs. I and II, consisted of two oscillators, two intensive controls, an electrical filter and two receivers, one for *O* and one for *E*. In so far as possible the two oscillators were identical in construction. Each oscillator was supplied with a Radiotron Model UX-210 tube. The filament terminal voltage was 7.5 while the current was kept constant at 1.2 amperes. A voltage of 180 was applied to the plate of the tube. The variable grid-bias was adjusted so that the tube operated on the straight part of the I_p–E_g characteristic. This characteristic was determined according to the method described in a publication by the *Bureau of Standards* on radio communication (4). No metallic objects were permitted in the vicinity of the oscillators. As previously explained, the Seashore tonoscope was used in calibrating the oscillators.

The intensive control for each oscillator consisted of an inductively coupled coil fastened to a slider which operated on a hard rubber rod 25 inches long. An inch scale of the same length was placed immediately above the hard rubber rod; this arrangement permitted *E* to read the positions of the inductively coupled coil.

The low-pass filter with a cut-off frequency of approximately 600 ~ was constructed according to the specifications given by

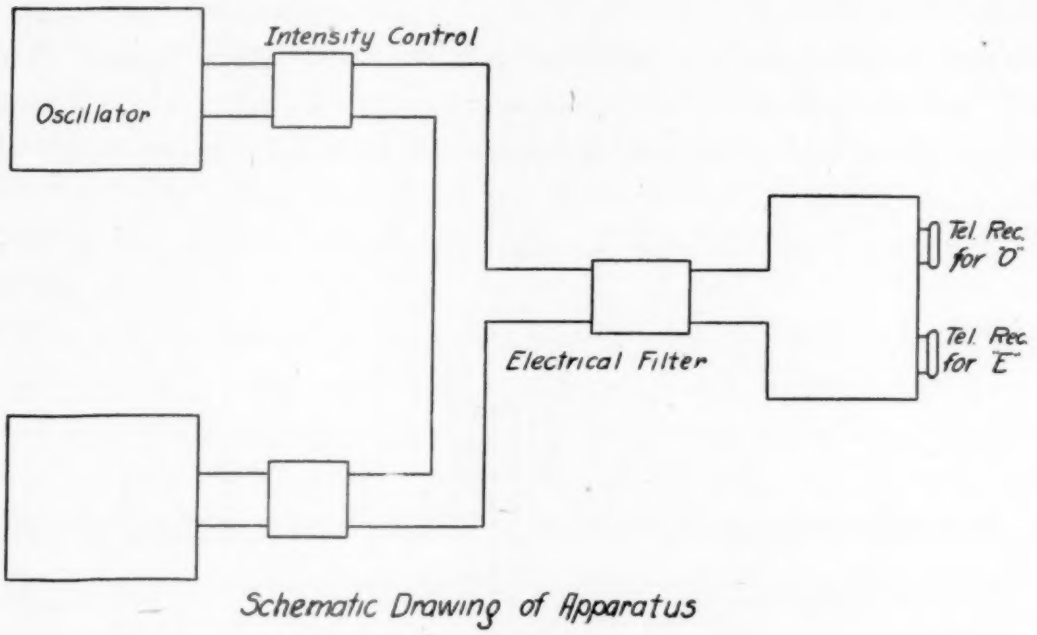

FIG. 1

Anderson (1). A consideration of various receivers led to the selection of the Western Electric 552 W receiver, "Type B." Two double pole, double throw switches made it possible for *O* to hear the tone from either oscillator alone.

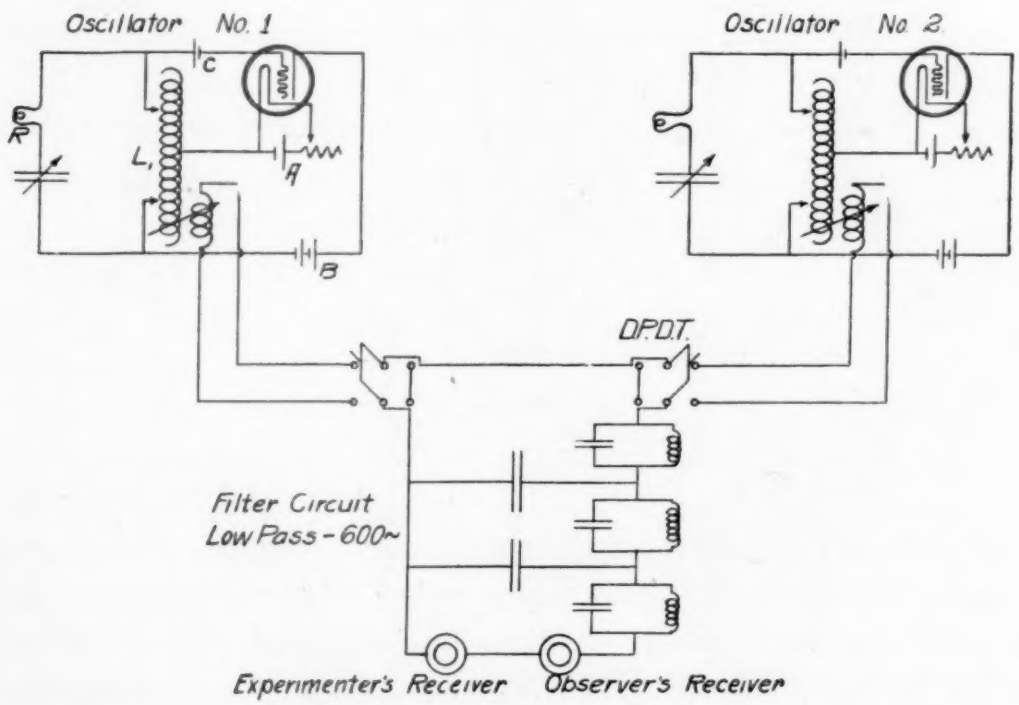

FIG. 2

Each of the tuning forks, Fig. III, was suspended by means of rubber bands fastened to the corners of the wooden base. Properly tuned resonators were placed in front of each fork. Rubber tubes connected with the resonators conducted the tones of the

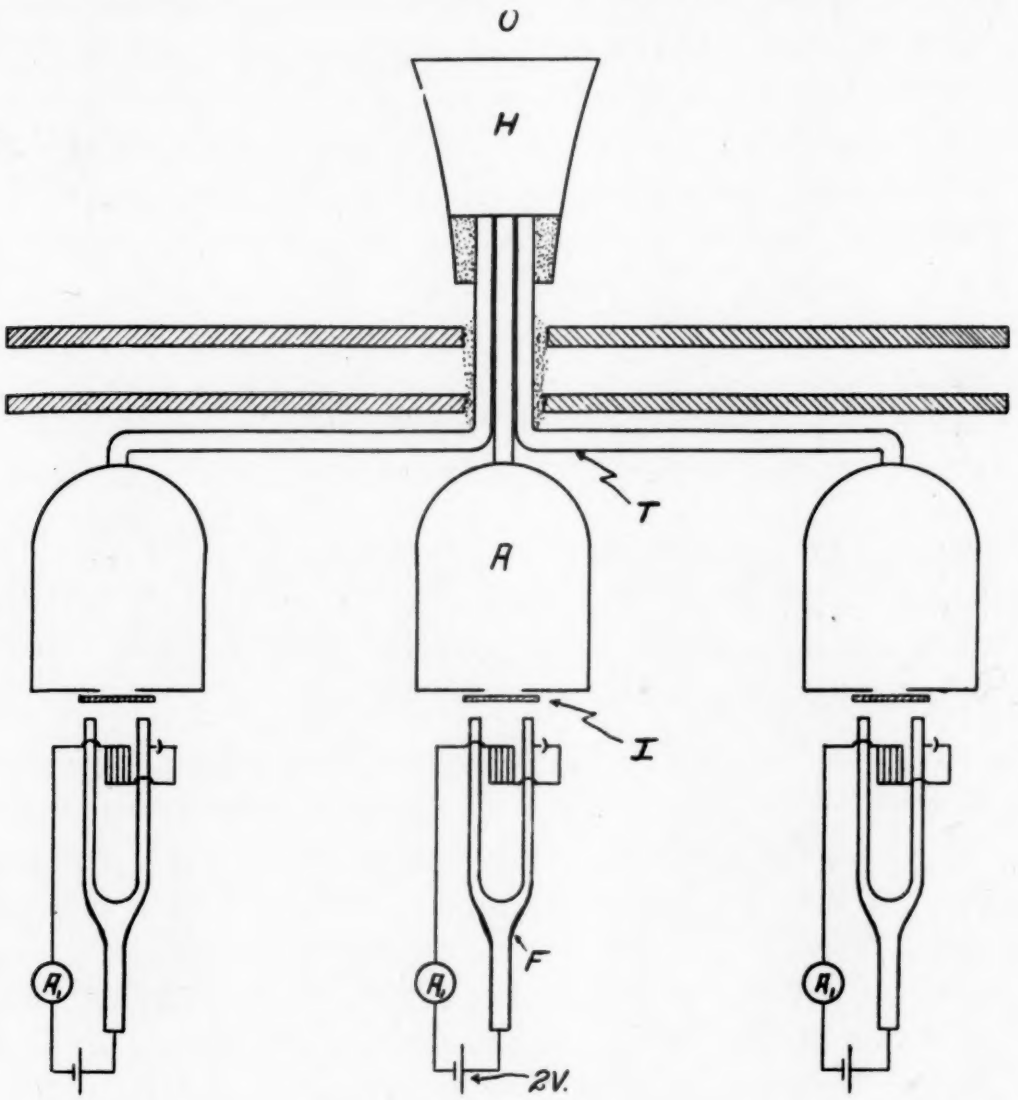

FIG. 3

Diagram of tuning fork apparatus

A Adjustable resonators
A_1 Milliammeters
F Tuning forks
H Horn
I Intensity control
T Rubber tubes

forks into an adjacent sound-proof room through a closely fitted opening in the wall. The tubes ended in a conical horn large enough to cover *O*'s ear. "Ozite" was packed around the tubes in the horn. The controls of intensity consisted of arrangements for varying the size of the openings of the resonators. The pri-

mary forks were identical in construction and were manufactured by Koenig. The amplitude of the vibrations of the tuning fork prongs was considered to be constant when the current, shown by the milliammeter readings, remained the same. A cardboard disc with an open sector of 180 degrees was placed so that its rotation covered and uncovered the opening of the resonator attached to the upper fork.

In addition to the oscillators and the tuning forks, two Stern tone variators were used as the source of the tones. The variator, (as described by *Stern* (**18**),) is a tone producing instrument of the blown bottle type. Its chief value in the present study lies in the facility with which its pitch is changed. In a series of tests on the tone variator *Sylvester* (**21**) found that the tone varies in pitch with a change in air pressure. The centrifugal air-pump of a vacuum cleaner was found to furnish a sufficiently constant air-pressure and was therefore used.

Phenomenological aspects of the beating complex; descriptions of the beating complex when the primaries are sounding at equal intensities. These descriptions were secured under the procedure and instructions of Series I. They served as a basis for drawing up the procedures and instructions used in the last six series of experiments. A study of the reports given by the three *O*s used in this series shows that two tones were heard when the difference in frequency of the primaries was 18 ~ or more, that two tones were not always reported when the difference was as little as 9 ~, that no *O* reported two definite tones when the difference was 6 ~, that the two tones began to lose their tonal quality when the difference of the primaries was 27 ~ or less, and that some *O*s designated the tones as 'a higher' and 'a lower' pitch. The descriptions reproduced below are typical of those on which the above statements are based. In the parentheses at the end of each description is found the symbol for *O*, the difference in frequency of the primaries and the intensive relations or changes of the primaries.

"The two tones which I could hear out were about a half-step apart. There was very little fusion of the two. I got only an unpleasant throbbing or beating. This throbbing seemed to constitute the unpleasant part of the

experience. If I could eliminate the throbbing, I believe all would be pleasant. By shifting attention I could change the pitch of the whole complex back and forth from a low to a high pitch." (E, 18 ~, 2,2)

"The beating was distinct and pronounced. I could not hear two distinct tones. The beating did not have a definite pitch. Its pitch shifted with a shift in attention." (B, 9 ~, 2,2)

"There was one tone and it was beating. The beating was not very rapid. I could hear only one tone and that was beating." (C, 6 ~, 2,2)

"There was only one tone; its pitch was quite definite. The rate of the beating was quite slow." (D, 6 ~, 2,2)

"I heard a fluctuation of pitch in the beating tone. There were higher and lower pitch points. I am not certain about whether there was a slurring of pitch in between these points. In addition I could get a dominant pitch of the whole sound. The rapidity of the fluctuation is identical with the rate of the beating. I can change the rhythm of the beats from four to six or more." (A, 6 ~, 2,2)

"I could not distinguish two separate tones. But there was a higher and a lower pitch. My first impression was that the complex had just one pitch. It seemed to be between the two pitches I could hear when I tried to analyze the complex." (E, 9 ~, 1,1)

"The first impression that I got was that there was just one pitch. It was beating. It seemed to be on the borderline of separating into two pitches. This pitch was not clearly defined. The beating was very prominent." (C, 12 ~, 2,2)

Other factors brought out in the reports are that *O*'s first impression of the beating complex was that it had one pitch which was not clearly defined, that when the two tones were not equally easy to hear the lower was the most difficult to hear out, that the pitch of the complex as a whole could be changed from a higher to a lower pitch by attending to the higher or lower tone in the complex and that the character of the beating complex changed with changes in the frequency differences of the primaries. The above statements are based on reports of which those reproduced below are typical.

"The beating was rapid and distinct. Two tones were heard. My first impression, however, was that the beating had just one pitch." (B, 18 ~, 2,2)

"My first impression is that the pitch of the complex is rather indefinite and difficult to place. It is like the pitch of the speaking voice; there is always a noisy quality connected with it. I can get either a high pitch or a low pitch out of the complex. Whichever pitch I hear is beating. It was easier to hear the higher pitch than the lower." (H, 24 ~, 2,2)

"This time I heard two pitches. a higher and a lower. But it was easier to hear the higher pitch. The lower pitch seemed to be much more covered up by the beating." (G, 24 ~, 2,2)

"The pitch of the complex as a whole seemed to take on the pitch of whichever tone I attended to. The beating was dominant." (B, 18 ~, 2,2)

"There was a dissonant effect of two tones. But there was also a beating effect of a different quality. The beating had a pounding, pushing character. But the beating was distinct from the dissonant effect." (B, 9 ~, 2,2)

"The outstanding thing was a vivid beating effect; the beat was rapid. The two tones were about a half tone apart. There was a slight roughness in the beats." (B, 18 ~, 2,2)

All but one of the eight *O*s reported a pitch fluctuation as well as a fluctuation in intensity when the differences in the frequencies of the primaries was ½ ~. These statements are based on reports of which the following are typical.

"The tone which I heard was fluctuating in intensity. When it became more intense, it seemed to go up in pitch but it dropped back suddenly as the intensity decreased." (H, ½ ~, 2,2)

"I heard a tone increasing and decreasing in intensity. The intensity change seemed to involve a pitch change also. At no time did the sound die away entirely." (C, ½ ~, 2,2)

"I heard a slow beating tone. Its intensity was changing regularly. A pitch change was associated with the intensity change." "I am not certain about this, but sometimes the more intense portions seemed to be higher in pitch." (D, ½ ~, 2,2)

"This time there was one tone. It was increasing and decreasing in intensity. Along with this intensity change there was a pitch change. As the tone became more intense it seemed to go down in pitch." (F, ½ ~, 2,2)

Descriptions of the beating complex when the primaries are sounding at unequal intensities. The instructions and procedures of Series II were used in securing these descriptions. An analysis of the reports secured from the seven *O*s when the difference in the frequencies was 24 ~, with the intensive relation 2,1, shows that in some cases *O*'s first impression was that the complex had a somewhat indefinite pitch, that this pitch was between the two pitches which were heard later, that there were two tones, that some *O*s preferred to refer to them as having pitch, that whenever their intensities were unequal, the higher pitched tone was the more intense and that the pitch of the complex could be changed by attending first to the higher and then to the lower tone. The following reports are samples of those on which the above statements are based:

"My first impression was that there was just one pitch, which was rather indefinite. Then I heard two pitches; both were beating. I could hear either one at will. If I just sat and listened the pitch of the sound would fluctuate back and forth. The first pitch which I heard was neither as high nor as low as the two pitches which I heard later." (C, 24 ~, 2,1)

"The beating was quite rapid. I could hear either a higher or a lower pitch. It was easier to hear the higher pitch. The sound as a whole has a dominant pitch which is different from either the higher or the lower pitch." (A, 24 ~, 2,1)

When the intensive relation 1,2 was used the reports show the above factors with the exception that the lower pitched tone was more intense when the two tones were heard as unequal in intensity. The reports which were secured with intensities at 3,1 or at 1,3 show that one tone was heard and that the beating was quite faint. The reports given below are typical of those on which the above statements are based.

"I heard only one tone. It was beating faintly." "There was a slight and quite rapid beating. Only one tone could be heard. The tone was almost smooth." (B, 24 ~, 3,1)

"There was a dominant tone which I heard at once. But it was not entirely smooth. It had a slight beating attached to it." "I heard one tone with a slight beating effect." (C, 24 ~, 3,1)

When the primaries were 12 ~ apart with intensive relation 2,1 or 1,2, the only difference in the reports was that the two tones were heard in a smaller percentage of the trials and that the beating was described as being slow and prominent. With the intensive relations 3,1 or 1,3 the reports showed that only one tone was heard and that the beating was very indistinct. The above results are not considered conclusive. They merely show that different procedures and more specific instructions are needed to determine the presence or absence of the phenomena reported. The experiments in the last five series were performed to answer these demands.

Descriptions of the beating complex when the primaries are reduced from maximal to minimal intensities and vice versa. These descriptions were secured under the procedures and instructions of Series III. A survey of the reports of the three *O*s, E, B, and D, used in this series shows that the beating complex as a whole became less intense and more intense when both primaries were reduced and increased in intensity, that two tones were heard more frequently when the intensities of both primaries were minimal and that two pitches were not heard in every case when the difference in the frequencies of the primaries was

reduced to 9 ~. The reports which are reproduced below are samples of those secured in this series.

"The beating became more intense at the same rate as the tones became more intense. The beating was rapid. Towards the end it was very difficult to distinguish the two tones." (E, 9 ~, 1–3:1–3)

"The beating became more intense and more prominent. As the intensity increased the beating had a sort of a plunger effect. The whole sound seemed to have one pitch." (B, 9 ~, 1–3:1–3)

"The intensity of the beating decreased. The two tones did not blend at all. Towards the end of the trial the beating was relatively less prominent." (D, 18 ~, 3–1:3–1)

"The whole complex increased in intensity. As the intensity increased the beating became relatively more prominent." (D, 18 ~, 1–3:1–3)

"There was an unpleasant throbbing effect; there was no blending of the two tones. Towards the end of the trial the lower tone had almost disappeared." (E, 27 ~, 3–1:3–1)

"The roughness effect diminishes when the tones decrease in intensity. As the intensity is decreased the lower tone becomes less and less prominent. As the intensity of the sound decreases the upper tone becomes smoother. Towards the end of the trial the interval effect had disappeared." (B, 45 ~, 3–1:3–1)

The experiments in Part I of Series X were performed as a check on these reports.

Descriptions of the beating complex when the intensity of one primary is increased at the same time as the intensity of the other primary is decreased. The procedures and instructions of Series IV were used in securing these descriptions. An analysis of the reports shows that seven of the eight *O*s at first heard one tone which had a faint beating effect; as the beating effect became more prominent, the pitch of the tone decreased gradually and continued to do so until the beating effect became faint again; the pitch change was continuous. The remaining *O* heard at first a tone which grew weaker; about the same time, as the beats became more prominent, a lower pitched tone appeared; then the beats became less prominent and the higher tone disappeared; the lower tone gained in intensity up to the end of the trial; at first the pitch of the complex was that of the higher tone; then the complex took on the pitch of the lower tone but it was difficult to note just when that happened. When the intensity of the upper primary was increased while that of the lower was decreased, the reverse of the above descriptions was secured. In some reports the beats were described as becoming more thrusting

and 'noisy' when the two primaries were equal or nearly equal in intensity and when the differences in the frequencies were 9, 12, or 24 ~. Additional factors brought out in some of the reports are that the complex does not have any definite pitch when the beats are the most prominent and that the beating seems quite independent of the rest of the auditory experience. Since the instructions did not require the *O*s to attend to any particular one of these factors, a statement as to the percentage of times reported has no significance. These reports, together with others, were the basis for performing the experiments in the last five series. The following reports are a sampling of those on which the above statements are based:

"At first I heard a tone which had a faint beat in it. The beat became more prominent; at the same time the pitch decreased gradually. Then the beat grew less prominent as the pitch continued to become lower. Just before the end of the trial the beat was very faint again. When the beat was most prominent, the pitch was blurred, *i.e.*, the beat did not have a clearly defined pitch." (B, 12 ~, 3–1:1–3)

"At first there was a tone which was beating faintly. Then the beat grew stronger; about the same time a lower pitched tone appeared and grew more intense as the beat became fainter. Towards the end of the trial the beat was very faint. The higher pitched tone had disappeared before that time. At the end of the trial the pitch of the complex as a whole was that of the lower tone but the pitch did not change gradually. Still I don't know just where it did change." (E, 12 ~, 3–1:1–3)

"It started with a relatively smooth tone which had faint irregularities in it suggesting a rudimentary beat. At first I was not sure whether the irregularities involved intensity or pitch changes or both. As the beat became more and more prominent, it became somewhat thrusting. The dominant pitch of the whole rose with the rise in the pitch prominence of the beats. The beating effect did not disappear entirely." (A, 12 ~, 1–3:3–1)

"It started out with a fairly smooth tone which gradually became lower in pitch and weaker. Then it became still lower and more intense until its intensity was equal to what it was at first. As the intensity became weaker, a fairly fast beat came in. This beat seemed to be somewhat separate from the tone." (D, 12 ~, 3–1:1–3)

"At first I heard a tone which had a faint beat attached to it. As this tone became more intense, its pitch went down and the beat became more prominent. This tone continued to decrease in pitch; towards the end it became more intense. The beat was fast and sounded more like a puffing than a tone. It was a noisy beat. The beat was not a part of the tone; it seemed independent." (D, 24 ~, 3–1:1–3)

"This time the pitch was higher at the end. At first the beats were very slight. The intensity of the tone decreased slightly. At the same time the beat became more prominent. The change to a higher pitch was gradual. In the middle of the trial the beats were more noticeable." (G, 24 ~, 1–3:3–1)

"At first there was one tone which was beating faintly. As the beat became

more prominent the pitch lowered. Toward the end of the trial it had become a lower pitched tone which had a slight beat. The pitch change seemed continuous. In the middle of the trial the beat was the most intense." (H, 24 ~, 3–1 :1–3)

Pitch variation in the beat. The observations on the pitch variation in the beat were secured under the procedures and instructions of Series V. Since the difference between the frequencies of the primaries was 1 ~, the rise and fall in the intensity of the resultant tone occurred once every second. In the following pages the points of maximal intensity will be referred to as the more intense portions while the points of minimal intensity will be referred to as the less intense portions of the beating tone. A study of the judgments made when the primaries were at 512 and 511 ~ shows that the more intense portions of the beating tone is judged higher in pitch from 75 to 100 per cent of the time by *O*s A, B, C and H regardless of the intensive relations of the primaries. The same *O*s hear the more intense portions as having a higher pitch when the upper primary is changed from maximal to minimal intensity once every second. These *O*s judge the more intense of two successive tones of the same frequency as higher in pitch also. F reports the more intense portion as lower in pitch from 70 to 100 per cent of the time regardless of the intensity relations of the primaries. When the upper primary is changed from maximal to minimal intensity once every second, this *O* heard the more intense portions as lower in pitch. F judges the more intense of two successive tones of the same frequency lower in pitch. Two *O*s, E and G, hear no pitch variations in the beating tone from 85 to 100 per cent of the time with one exception on the part of G when the percentage is 55 for intensive relation 2,2. These two *O*s hear no pitch changes when the higher primary is changed in intensity once every second, but one of them does judge the more intense of two successive tones of the same frequency higher in pitch. With none of the three intensive relations does D hear the more intense portions as higher, lower or the same in pitch more than 40 per cent of the time, but when the intensity of the upper primary is varied once per second, D hears the more intense portions as

higher in pitch. D also reports the more intense of two successive tones of the same frequency as higher in pitch. In a small percentage of the reports three *O*s state that they hear the more intense portion as having a low pitch during part of the trial and a high pitch during part of the trial. One *O* goes further in some of the reports and states that the intense portion can be heard as having either a high or a low pitch adding, in more than 75 per cent of those reports, that it is much easier to hear the more intense portions as having a higher pitch.

When the primaries had frequencies of 256 and 255 ~, respectfully, the results show that A and C report the more intense portions of the beating tone to be lower in pitch regardless of the intensive relations of the primaries; this is the opposite of the reports given by these two *O*s when the primaries were at 512 and 511 ~. It is to be noticed, however, that when the upper primary is changed from maximal to minimal intensity once every second, A and C continued to judge the more intense portions lower in pitch. Furthermore, these *O*s report the more intense of two successive tones of the same frequency lower in pitch. The results for all the other *O*s with the exception of D, whose reports now agree with those of E, are not different from those given when the primaries had frequencies of 512 and 511 ~.

The results of the experiments in this series are not in agreement with those obtained by *Helmholtz* (**9**, p. 415) and *Taylor* (**22**). According to these investigators the pitch of the more intense portions of the beating tone is (1) lower when the upper primary is the more intense, (2) higher when the upper primary is the less intense, and (3) the same as the less intense portions when both primaries are equal in intensity. Our experiments show regardless of the intensity relations of the primaries (1) that the *O*s, who hear the more intense portions as having a higher pitch, also judge the stronger of two successive tones of the same frequency higher in pitch, (2) that the *O*s, who hear the more intense portions as having a lower pitch, also judge the stronger of two successive tones of the same frequency lower in pitch, and (3) that the *O*s, who hear no pitch variation, also hear no change in pitch when the intensity of one primary is changed

from maximal to minimal at the rate of the beating of the two primaries. The results indicate that the judgments on the pitch variations in a beating tone follow the law which governs the illusion of pitch due to the difference in the strength of two successive tones of the same frequency. The illusion of pitch due to the strength of a tone varies in direction from *O* to *O* and varies in direction for the same *O* when different frequencies are used. The latter results are in agreement with those reported by *Hancock* (7).

Relation of pitch changes in the beating complex to the appearance of beats. The procedures and instructions of Series VI were used in securing the results presented below. As previously explained the intensity of the upper primary was decreased by moving the intensive control coil for the upper primary away from a zero reading on the 25 inch scale; a mechanical arrangement made possible an increase in the intensity of the upper primary by having its intensive control coil moved along the inch scale to a lower reading. In every case the obtained difference between the average of the points at which a lower tone appears and the average of the points at which the beats appear is more than ten times the standard error of the difference between the two averages (6). Each average is based on 30 judgments. This is true also when the obtained difference between the average of the points at which a higher tone appears and the average of the points at which the beats appear is considered. The results show that B is aware of the beats sooner than and continues to hear them longer than E. B's comment explains this difference: " Shortly before I hear the beats plainly I have a feeling of something different; the smoothness is interrupted; I feel that beats are coming; I signalled just when the smoothness disappeared; I signalled the second time when the smoothness came back; it is more difficult to note where the beats disappear." E states: " My first signal was when I was sure that there was a beat; my second signal was given when the beat disappeared." The data show (1) that the beats are present before a lower pitched tone is heard when the intensity of the upper primary is decreased, while that

of the lower is increased, and (2) that beats are also present before a higher pitched tone is heard when the intensity of the upper primary is increased while that of the lower is decreased.

Analysis of the beating complex. The results presented below were secured under the procedure and instructions of Series VII. When the difference between the primaries was 6 ~, four *O*s heard just one tone which was beating. When the two *O*s, who reported two tones, were asked to describe the tones, one stated, "There are higher pitch points and lower pitch points in the beating complex, *i.e.*, there is not a continuous low tone. These points of higher and lower pitch lack tonal quality; the beat is too rapid to note whether there is a continuous change in pitch between these points; my first impression was that the beat had just one dominant pitch." The other *O* made the comment, "The beat has a lower and a higher point in it which I can hear when I attend closely." These quotations show that two continuous pitches were not heard by these two *O*s.

When the two primaries were equal in intensity and had a difference in frequency of 12 ~, five *O*s heard two tones. Two tones continued to be heard by four of these when the intensive relation was 3,2 and by two *O*s when the intensive relation was 2,3; with intensive relations 3,1 and 1,3 only one *O* reported two tones and that was under intensive relation 3,1.

When the primaries were 24 ~ apart the only difference was that now all *O*s with the exception of one heard two tones under the intensive relations 3,2 and 2,2 and the same was true for all but two *O*s when the intensive relation was 2,3. No *O* reported two tones when the intensive relations were 3,1 and 1,3.

Several of the *O*s made frequent comments on their observations. A, C and H often reported that their first impression of the beating complex was that it had just one dominant pitch. The following description, secured from A when the frequency difference was 12 ~, touches on the quality of the dominant tone.

> "My first impression was that the beating complex had one dominant pitch. The higher and the lower pitches were almost equally prominent. When I attended to the dominant it was a continuous thing; it was like a kind of overlay over this rough beating which consisted of two extremes of pitch. The beats were thrusting and pointed."

The comments of B and D were to the effect that the beating seemed to become quite detached from the tones which were heard. The following comment from B, when the intensive relation was 3,2 and the difference in frequency 24 ~, is typical as an illustration of the above statement:

"The higher pitch was the more intense, but a lower pitch was definitely there. The beat seemed to be an accompanying effect somewhat independent of the pitches I heard."

Under similar conditions H made the following comment:

"My first impression is that the pitch of the complex is rather indefinite and hard to place. There is always a noisy quality connected with it. When I attempted to analyze the complex I got either a high pitch or a low pitch out of it. Whichever pitch I heard was beating. The dominant pitch seemed to be somewhere between the high and the low pitch which I heard."

Stated in more general terms, the results show that two tones are heard in the beating complex when the frequency difference of the primaries is 12 ~ or more at this pitch level (512 ~) and when the primary tones are equal or nearly equal in intensity.

Pitch changes in the intertones. The tones of the beating complex whose pitch lies between those of the primary tones are designated intertones. The results expressed below were secured under the instructions and procedure of Series VIII. When a percentage of 70 is taken to show that the judgments are significant,[3] a statistical treatment of the judgments shows that the dominant pitch of the beating complex changed whenever either one of the primaries was changed in intensity from maximal to medium and from medium to minimal and *vice versa.* The only exception to the above statement occurred in the reports given by F when intensive relation 2,2 was changed to 2,3 and *vice versa.* When the highest and the lowest pitches in the beating complex are considered, the results show that under the intensive changes stated above the highest pitch changed 16 times out of a possible 28 and the lowest 13 out of a possible 28, whereas the dominant

[3] Using the formulas given by *Rietz* (**15**) a percentage of 70, which is 36.7 per cent above 33.3, the per cent which is due to chance is 3.760 times the probable error, .0976, of the obtained difference when 20 cases are used, *i.e.*. the chances are 9942 out of 10,000 that the true difference will always be greater than zero.

pitch changed 34 times out of a possible 35. As previously stated the above statements refer to situations in which either one of the primaries was changed in intensity from maximal to medium and from medium to minimal and *vice versa*. When the intensive change involved both primaries, the dominant pitch changed 28 times out of a possible 28, the highest changed 19 out of a possible 21, and the lowest changed 21 out of a possible 21 times.

The results show also that there is a tendency to judge the highest pitch as unchanged more frequently when the upper primary remains constant at maximal intensity than when it is involved in the intensive changes. The same tendency is shown on the part of the lowest pitch when the lower primary is at maximal intensity and is not involved in the intensive change. When the intensive relations of the primaries are changed, the dominant pitch changes most, the highest pitch changes less and the lowest pitch changes the least.

Comparison of the pitch of the intertones with the pitch of tones having known frequencies. The results of the experiments performed under the instructions and procedures of Series IX are presented in Tables I and II. The purpose of the series was to determine the pitch of the dominant, of the higher, and of the lower tones in the beating complex by comparing these with tones whose frequencies were known. Table I gives the results for each *O* when the indicated intensive relations, instructions and compared tones were used. The primaries were at 512 and 488 ~. The compared tones had frequencies of 512, 506, 500, 494 and 488 ~.

If *O* judges the dominant tone to be the same in pitch as a tone of 500 ~ and the highest tone to be higher in pitch than a tone of 500 ~ when the primaries have a given intensive relation, it is evident that with this particular intensive relation the dominant tone has a lower pitch than the highest tone in the beating complex. The above assumption makes it possible to use the data presented in Table I in determining under what intensive relation of the primaries the dominant tone is lower in pitch than the highest tone and higher in pitch than the lowest tone. As an

TABLE I. *Per cent of times that a tone of a known frequency was judged higher, lower, or the same in pitch as the dominant, the highest and the lowest tone in the beating complex when the difference in the primaries was 24 ~ with the upper primary at 512 ~*

		With 512 ~						With 506 ~														
		3,1			3,2			3,1			3,2			2,2			2,3			1,3		
Os	Instructions*	H	L	S	H	L	S	H	L	S	H	L	S	H	L	S	H	L	S	H	L	S
A	1	85		15	100				95	5	100			100			100			100		
	2	15		85	100				100		75		25	100			100			100		
	3	85		15	100			35	20	45	100			100			100			100		
B	1	100			100				90	10		80	20	90		10	100			100		
	2			100	100				100			90	10	15		85	100			100		
	3	90		10	100			30	30	40	40	15	45	100			100			100		
C	1	85		15	100			25		75	75		25	90		10	100			100		
	2			100	100			100			10	20	70	75	15	10	100			100		
	3	90		10	100			95	5		100			100			100			100		
E	1	100			100				15	85	100			100			100			100		
	2	15		85	100				90	10	10		90	100			100			100		
	3	100			100			90		10	100			100			100			100		
G	1	75		25	100				100			25	75	100			100			100		
	2			100	100				100			70	30	15	10	75	100			100		
	3	100			100			5	95		50	45	5	100			100			100		
H	1	100			100			5	15	80	100			100			100			100		
	2	10		90	100				80	20	25	40	35	100			100			100		
	3	100			100			100			100			100			100			100		

* Under instructions Nos. 1, 2 and 3, *O* attended to the dominant, the highest and the lowest pitch, respectively, in the beating complex and judged if the second tone was higher, lower, or the same in pitch.

illustration of the method let us take the case of A who judged a tone of 512 ~ higher than the dominant 85 per cent of the time and higher than the highest tone in the complex 15 per cent of the time. The obtained difference between these percentages is 60. This difference shows that the dominant tone is lower in pitch than the highest tone in the complex. Using the formulae given by *Rietz* (15), an obtained difference of 40 between two percentages is found to be 4.09 times the probable error of the difference when the per cent due to chance is 33.3 and when 20 cases are used. Consequently, an obtained difference of 40 or more is considered significant. A survey of Table I shows that the dominant tone was judged lower in pitch than the highest tone in the complex by all *O*s when the intensive relation was 3,1, by all *O*s except A when the intensive relation was 2,2, by only one *O* when the intensive relation was 2,3 and by only one *O* when the intensive relation was 1,3. That the results from four *O*s show no significant difference between the dominant and the highest tone in the complex when the intensive relations were 2,3 and 1,3 may be due to the fact that the compared tones did not have small enough gradations in frequency. We can conclude, however, that if there is a difference in the pitch of the dominant tone and the highest tone, it is less than it was under the previous intensive relations. The dominant tone was judged higher in pitch than the lowest tone by all of the *O*s when the intensive relations were 3,1 and 3,2, by B and C when the intensive relation was 2,2, by none of the *O*s when the intensive relation was 2,3, and by all of the *O*s when the intensive relation was 1,3. The highest tone in the complex was judged higher in pitch than the lowest tone by all *O*s in all the intensive relations with the exception of relation 2,3. These results show that the dominant, the highest, and the lowest tones are different in pitch from each other; they also indicate that the more intense the lower primary becomes in proportion to the upper, the less frequently is the pitch of the highest tone in the beating complex judged as different from that of the dominant tone.

If a tone is judged the same in pitch as a second tone of 506 ~, the former should be judged higher in pitch than a tone of 500 ~.

TABLE I—*Continued*

		With 494 ~													With 488 ~						With 500 ~											
		3,1			3,2			2,2			2,3			1,3				2,3			1,3				3,1			3,2			2,2			2,3			1,3		
Os	Instructions*	H	L	S	H	L	S	H	L	S	H	L	S	H	L	S	H	L	S	H	L	S	H	L	S	H	L	S	H	L	S	H	L	S	H	L	S
A	1		100			100		30	45	25	100			100				100			100					100			85	15	100			100			100		
	2		100			100		10	90		100			100				100			100					100			100			15	65	20	100			100		
	3		100			45	55	50	10	40	100			100				100			25	75		40	15	45	90		5	5				100			100		
B	1		100			75	25	50			50	100			100			100			60	40			100			10	25	65	100			100			100		
	2		100			100		35			65	100			100			100							100				80	20	60		40	100			100		
	3		100		10	15	75	90			10	100			100			100				100		45	10	45	75		5	20	100			100			100		
C	1		100			100		5	50	45	100			100			75	25		75	25			100			5	40	55	100			100			100		
	2		100			100			90	10	100			100			100			85	15			100				100		5	90	5	95		5	100		
	3		100			25	75	85			15	100			100		75	25				100		70	15	15	100			100				100			100		
E	1		100			100		85			15	100			100			100			95	5			100			5	60	35	100			100			100		
	2		100			100		20	10	70	100			100			100			95	5			100				100		15		85	95		5	100		
	3		100		30	10	60	90			10	100			100		95	5		10	90			55		45	100			100				100			100		
G	1		100			100			10	90	100			100				100			55	45			100				30	70	100			100			100		
	2		100			100		100			50	50	85	15				100							100						100			100			100		
	3		100		15	35	50	30			70	100			100			55	45			100			5	15	80	75		25	100			100			100		
H	1		100			100		85	5	10	100			100				90	10		85	15			100				50	20	30	100			100			100		
	2		100			100		5	90	5	100			100				100							100						100			100			100		
	3		100		85		15	100			100			100				100			15	85		65		35	100			100		30	100			100		

* Under instructions Nos. 1, 2 and 3, *O* attended to the dominant, the highest and the lowest pitch, respectively, in the beating complex and judged if the second tone was higher, lower, or the same in pitch.

Similarly if a tone is judged the same in pitch a certain percentage of the time as a second tone of 506 ~, the former should be judged the same in pitch as a second tone of 500 ~ a smaller percentage of the time. A survey of Table I from the point of view of the above statements shows that all *O*s display this tendency in their judgments of pitch. The only exception is found in the reports of A, B and G on the pitch of the lowest tone when the intensive relation of the primaries was 3,1. This exception indicates that the lowest tone in the complex has a more indefinite pitch than the dominant or the highest pitch. This is an agreement with the comments by these *O*s and others to the effect that it was very difficult to place the pitch of the lowest tone.

A survey of Table I from the point of view of determining the pitch of the dominant tone when both primaries were equal in intensity shows that all the Os judged the dominant and the lowest tone in the beating complex lower in pitch than a tone which had a frequency midway between the two primaries.[4] On the other hand only one *O*, H, judged the pitch of the highest tone in the complex lower than a tone whose frequency was midway between the primaries. When the dominant, the highest, and the lowest tones were compared to a tone whose frequency was three-fourths of the distance towards the lower primary, the dominant tone continued to be judged lower in pitch by E and H; no *O* judged the highest tone in the complex lower than the comparison tone and no *O* judged the lowest tone in the complex higher than the comparison tone. In the above cases the intensity of the primaries was equal.

When the compared tone had a frequency three-fourths of the distance towards the upper primary and when the intensities of the primaries were equal, the dominant tone and the lowest tone in the beating complex were judged lower in pitch by all *O*s, but the highest tone was judged the same in pitch as the compared tone by B and G and lower than the compared tone by the other *O*s. Furthermore Table I shows that the dominant tone was never judged the same as either the upper primary tone or

[4] A percentage of 70 is taken to show that the judgments are significant. For an explanation see previous footnote.

the lower primary tone. But when intensive relation 3,1 obtained between the primaries, the highest tone was judged the same as the upper primary by all *O*s and the lowest tone in the complex was judged the same as the lower primary by all *O*s when intensive relation 1,3 obtained between the primaries.

Table II gives the per cent of times that a tone of a known frequency was judged higher, lower or the same in pitch as the dominant, the highest and the lowest tone in the complex when the difference in the frequencies of the primaries was 12 ~. The table shows that the dominant tone was judged lower in pitch than the highest by A, G and H in intensive relation 3,1, by only H in intensive relation 3,2, by E, G and H in intensive relation 2,2, by all *O*s in intensive relation 2,3 and 1,3.[5] That the dominant tone was judged higher than the lowest tone in the complex is true for all except two *O*s in the intensive relation 3,1, for all except one *O* in intensive relations 3,2 and 2,2, for only one *O* in intensive relation 2,3 and for three *O*s in intensive relation 1,3. The table shows also that the highest tone is judged higher in pitch than the lowest tone in the complex regardless of the intensive relation of the primaries. The fact that the results do not show a significant difference in the tones of the complex in some of the intensive relations can not be taken to show that there is no difference in pitch. It may be due to the fact that the compared tones did not have small enough gradations in frequency. Table II demonstrates also that the tones in the beating complex show a change in pitch in the expected direction when the intensive relations of the primaries are changed.

When the primaries were 24 ~ apart and equal in intensity, the pitch of the dominant tone was found to be lower in pitch than a tone midway between the primaries in frequency. Table II shows that when the difference in frequency is 12 ~, H judged the dominant tone lower, B judged it higher, and E judged it the same in pitch as a compared tone midway between the primaries in frequency; the remaining *O*s judged it lower and the same in pitch about an equal number of times as the compared tone. As

[5] A difference of 40 in the percentages is accepted as showing a significant difference.

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TABLE II. *Per cent of times that the tone of a known frequency was judged higher, lower or the same in pitch as the dominant, the highest and the lowest tone in the beating complex when the difference in the primaries was 12 ~ with the upper primary at 512 ~.*

		With 512 ~						With 506 ~															With 500 ~					
		3,1			3,2			3,1			3,2			2,2			2,3			1,3			2,3			1,3		
Os	Instructions*	H	L	S	H	L	S	H	L	S	H	L	S	H	L	S	H	L	S	H	L	S	H	L	S	H	L	S
A	1	90		10	100				100			100			5	65	30	100			100				100			55	45
	2		15	85	100				100			100			100			10	15	75	100				100			95	5
	3	95		5	100				100		45		55	100				100			100				100			5	95
B	1	10		90	100				100			100			85	15	100			100				100			5	95
	2			100	100				100			100			100			5		95	100				100			55	45
	3	95		5	100				100			65	35	55		45	100				100			90	10			100	
C	1	10		90	100				100			100			5	45	50	100			100			85	15			100	
	2	5		95	100				100			100				75	25		70	30	100			90	10		15	85	
	3	75		25	100				100		90		10	100				100			100			30	70			100	
E	1	20		80	100				100			100			30	70	90		10	100				95	5		10	90	
	2	15		85	100				100			100			90	10	10	15	75	100				100			90	10	
	3	100			100				100		85		15	90		10	100				100			100				100	
G	1	85		15	100				100			100			45	55	75		25	100				100			70	30	
	2	5		95	100				100			100			100		10	5	85	100				100			100		
	3	100			100				100		40		60	35		65	100				100			95	5			100	
H	1	95		5	100				100		10	40	50	85		15	100				100			100			90	10	
	2	35		65	100				100			100		5	90	5	5	50	45	100				100			85	15	
	3	100			100			60	20	20	90		10	100			100				100			100			45	55	

* Under instructions Nos. 1, 2 and 3, *O* attended to the dominant, the highest and the lowest pitch, respectively, in the beating complex and judged if the second tone was higher, lower, or the same in pitch.

previously explained, a percentage of 70 or more is accepted as showing a significant difference. All *O*s judged the highest tone in the complex higher in pitch than the compared tone; no *O* judged the lowest tone the same as or higher than the compared tone when the primaries were equal in intensity and when the compared tone was midway between the primaries in frequency.

In addition to the above factors Table II shows that the dominant tone was judged the same in pitch as the upper primary by B, C and E when intensive relation 3,1 obtained between the primaries; the same *O*s judged the dominant tone the same in pitch as the lower primary. When the intensive relation 3,1 obtained between the primaries, the highest tone was judged the same in pitch as the upper by all *O*s except one and the lowest tone was judged the same in pitch as the lower primary by all *O*s. On the basis of these findings we conclude that the difference between the pitch of the dominant tone and that of the lowest tone becomes less as the lower primary becomes relatively more intense and the difference in pitch between the dominant tone and the highest tone in the beating complex becomes less as the upper primary becomes relatively more intense.

When the primaries were 6 ~ apart and equal in intensity, the dominant tone was judged higher in pitch than a compared tone whose frequency was midway between the primaries by all *O*s except E, who judged it the same in pitch.[6] When intensive relation 3,1 obtained between the primaries, three *O*s judged it the same and three *O*s judged it lower in pitch when it was compared with the upper primary. The dominant was reported higher in pitch than the lower primary by four *O*s and the same in pitch as the lower primary by two *O*s when the intensive relation of the primaries was 1,3.

Effect of intensive changes and differences in frequencies on the quality of the beats. The results of the experiments in Part I of Series X, which were performed to determine how the beating complex changed in quality when the intensive relations of the primaries were altered, show that all *O*s reported a change in the

[6] A percentage of 70 is taken as showing a significant difference.

beating complex with a change in the relative intensities and the absolute intensities of the primaries when these were 24 ~ apart. Since *O* was not instructed to note if the beating complex changed in certain specific ways, the results are not expressed in terms of the per cent of times which *O* reported the change to take place.

The following statements are based only on those factors which are mentioned in half or more of *O*'s descriptions. *O*'s instructions were: "Attend to the beating complex and observe whether it changes in any way outside of pitch; you will be asked to describe your experience." These instructions were purposely left in a rather vague form in order to draw out a phenomenological report from *O*. We wished to obtain an account that was as naïve and free from suggestion as possible.

When intensive relations 3,1 and 2,2 were compared, C described the second as having a more 'thrusting', more 'pointed', 'bigger', slower and less 'blurred' beats. D described the second as having a more 'dominant', 'louder', 'thrusting' and 'bigger' beat. Under the same conditions F reported the second to be 'duller' and 'darker' with a slower beat. The beats in the second were described as being more 'prominent', 'distinct' and 'pointed' by B. G reported that the beats were more 'even' and less 'sharp' in the second.

When intensive relations 3,1 and 1,3 were compared, the reports of all *O*s show that fewer differences were noted in the beating complex. The following description is typical of those given by C. "There was not much difference in the beating effect; in the second the beating was slightly more prominent; the beats seemed to be bigger and they also seemed to have a slower rate. In the first part the beats seemed quite detached from the tone." D agreed with C in reporting that "the beating was more closely identified with the tone in the second." F reported that the beat in the second "had more volume" and "seemed to occupy more space." To B the beat was slightly more prominent in the second. G reported that there was no change in the rate of the beat and that the beat was not as 'sharp'.

When intensive relations 2,2 and 1,3 were compared. C re-

ported that the beats were less 'prominent', less 'pointed', less 'distinct', more 'rapid' and more 'blurred' in the second. According to D the beating effect in the second was less 'dominant', less intense and less 'thrusting'. F noted that the beat had more 'volume' and that it was less 'prominent', less 'distinct' and less 'pointed' in the second. According to G the "whole effect was more intense, but the beating was less distinct."

A change in the quality of the beating complex was reported by all *O*s when intensive relations 2,2 and 3,3 were compared. According to C ". . . the whole effect was louder; the beating seemed slightly less rapid in the second, but it was more thrusting and pointed." D reported that in the second the beat was more intense and more 'thrusting'. F described the beat in the second as more intense while B and G described it as more prominent and 'pointed'.

The above results show that the quality of the beating complex is dependent both upon the relative and absolute intensities of the primaries. They indicate, furthermore, the necessity of controlling the intensities of the primaries when the effect of the difference in frequency on the quality of the beat is studied. The reports secured from C show that the rate of the beat increases as the primaries approach equality in intensity and as the primaries increase in intensity at the same time.

The experiments in Part II of Series X were performed to determine if the *O*s used Myers' terms, surging, thrusting, rattling and rough, in describing the quality of the beating complex when the beating complexes which are associated with frequency differences of 8, 16, 28 and 44 ~, respectively, were compared with each other. A study of the reports from the first two *O*s used showed that the terms surging, thrusting, rattling and rough were not used in describing the beat when the primaries differed in steps of 8, 16, 28 and 44 ~, respectively. The only one of the above terms used was 'rough' and that was frequently used to apply to the beat when the frequency difference was 28; the term was used once when the difference in frequency was 44 ~. In addition, the reports showed that an overtone was heard occa-

sionally and that a continuous 'buzzing' was present. These factors point to the limitations in the use of the Stern variators.

A survey of the descriptions and comments which have been secured when the intensive relations of the primaries were equal and when no descriptive terms had been given in *O*'s instructions shows that some terms were used more frequently than others in describing the beating complex when the primaries had certain differences in their frequencies. A single tone which was fluctuating in intensity as well as pitch was heard when the primaries were from one-half to 1 ~ apart. When the difference in their frequencies was 6 or 9 ~, the beat had taken on a 'pounding', 'pushing' and 'thrusting' character. At a difference of 12 ~ with the upper primary at 512 ~ the beat had become still more thrusting and rough. The term, throbbing, was frequently ascribed to the beat and the rough character of the beating complex had become more evident when the primaries were 18 ~ apart with the lower primary at 256 ~. At a difference of 24 ~ with the upper primary at 512 ~ the beat was described as 'noisy', 'rattling' and 'puffing', but with the lower primary at 256 ~ and the difference in frequency 27 ~, the terms, 'purring' and 'throbbing', were applied frequently to the beat. At a difference of 36 ~ the rough quality of the beating complex was outstanding. When the difference in the frequencies was increased to 45 ~, the individual beats were no longer perceptible and the rough character had become more evident. Furthermore, the beats were reported to be somewhat detached from the tones which were heard in the complex whenever the primaries were 24 ~ or more apart.

An adequate study of the change in quality of the beating complex as the difference in the frequencies of the primaries is increased constitutes a separate problem requiring additional apparatus and a new group of *O*s. It is beyond the scope of the present study. For such a study neither audio-oscillators with the present types of available receivers nor Stern variators are recommended as the source of tones. The study requires that several sets of electrically driven tuning forks, whose frequencies

differ in small steps, be available and that each set cover sections of the tonal range at octave intervals.

Summary and conclusions. In the present investigation of the beating complex, in which audio-oscillators, electrically driven tuning forks and Stern variators were used as the source of the tones, the following results were obtained.

Under the instructions, " You will be presented with auditory stimuli which you will be asked to describe ", a series of descriptions were obtained (1) when the primaries were sounding at equal intensities and at various differences in their frequencies, (2) when the relative intensities of the primaries were unequal, and (3) when the intensities of the primaries were gradually reduced from maximal to minimal intensity and *vice versa* while *O* listened. These descriptions were used as the basis for drawing up the procedures and instructions for the main part of the study.

The results of this study show that when *O* listened to the beating complex while the intensity of one of the primary tones was reduced gradually and at the same time as the intensity of the other primary tone was increased, a single tone which had a faint beat was at first heard; then, as *O* continued to listen, its pitch changed gradually (the change in pitch was always in the direction of the primary tone which was being made more intense); as the pitch changed, the beat became more prominent; the tone continued to change in pitch in the same direction until the beat became faint again. When the beat was the most prominent, the tone had a less definite pitch. The above phenomena were observed when the difference in frequency of the two primary tones ranged from 6 to 24 ~.

The results of our experiments which concerned the pitch variation in the beats are not in agreement with those obtained by *Taylor* (22) and *Helmholtz* (9, p. 415). These two investigators report that the pitch of the more intense portions of the beating tone is (1) lower than the less intense portions when the upper primary is the more intense, (2) higher when the upper primary is the less intense, and (3) the same as the less intense

portions when both primary tones are equal in intensity. Regardless of the intensive relations our experiments show (1) that the *O*s who heard the more intense portions as having a higher pitch also judged the stronger of two successive tones of the same frequency higher in pitch, (2) that the *O*s, who heard the more intense portions as having a lower pitch also judged the stronger of two successive tones of the same frequency as being lower in pitch, and (3) that the *O*s who heard no pitch variations also heard no change in pitch of a tone whose intensity was changed gradually from maximal to minimal once every second over a period of 60 seconds. Our results show that the judgments of the variations in pitch in a beating tone follow the law which governs the illusion of pitch due to the difference in the strength of two successive tones of the same frequency. Our results are more in accord with *Stumpf's* (20, p. 478) observation to the effect that one hears in slow beats only one tone of constant pitch.

When *O* listened while the upper primary tone was decreased in intensity at the same time as the lower was increased and when the intensive change occupied more than 20 seconds, the first factor perceived was the beat; then later, as *O* continued to listen, a low pitched tone was heard. The beat was also perceived before a high pitched tone was heard when *O* was listening while the upper primary was increased in intensity at the same time as the lower was decreased.

When the intensities of the primaries were equal or nearly equal and when the difference in frequency was not less than 9 ~ or more than 24 ~, the beating complex had (1) one dominant tone, the pitch of which was not clearly defined, when *O* was instructed to avoid any attempt at analysis, and (2) one higher and one lower pitched tone when *O* was instructed to analyze his auditory experience. Through the method of comparing these with tones of known frequencies we found that none of the tones in the complex were as high in pitch as the upper primary nor as low in pitch as the lower primary. Furthermore, the dominant, the higher and the lower tones in the complex were (1) higher in pitch whenever the upper primary was relatively more intense and

(2) lower in pitch whenever the lower primary was relatively more intense. The differences between the pitches of the dominant, of the higher, and of the lower tones were found to be less whenever the differences in frequency between the primary tones were less. When the upper primary was relatively more intense, the difference in pitch between the higher tone and the dominant tone was less. Similarly, the difference between the pitch of the dominant and the lower was less whenever the lower primary tone was relatively more intense.

Some of the above findings are in partial agreement with those obtained by previous investigators. Among them are those secured by *Eberhardt* (5) who reports that two tones are heard when the primaries are more than 8 ~ apart and when they are equal in intensity and that the pitch of one of these intertones is near that of the upper primary while the pitch of the other is equally near that of the lower primary when the frequency of the lower primary was 660 ~. Our study, however, shows that the higher intertone is not as close to the upper primary in pitch as the lower intertone is to the lower primary. That only one tone is heard in the beating complex is the view of *Titchener* (24, p. 105), *Stumpf* (19, 20) and *Bosanquet* (3), but they add that the primary tones themselves are heard when the difference in the primaries reaches a certain number of vibrations. This critical difference is 32 ~ with the lower primary at 256 ~ for *Titchener,* 22 ~ with the lower at 418 ~ for *Stumpf,* and 12.8 ~ with the lower primary at 512 ~ for *Bosanquet. Myers* (14, pp. 37–38) and *Bentley* (2) are not specific with reference to the differences in frequencies at which the two primaries are heard in addition to the beating intertone.

That the pitch of the intertone is approximately midway between that of the primary tones when these are equal in intensity is the view of *Bosanquet* (3), *Meyer* (12), *Eberhardt* (5) and *Stumpf* (20). Our results in so far as they relate to the pitch of the dominant tone of the beating complex are in partial agreement with these views. Our study shows that with a difference in frequency of 6 ~ and with equal intensities of the primaries the

dominant pitch of the beating complex was judged to be closer to the upper primary tone by all *O*s except one who judged it to be the same in pitch. When the difference in frequency was increased to 12 ~, the dominant tone was judged to be closer to the lower primary in pitch by one *O*, closer to the higher primary by another *O*, midway between by a third *O* and both midway and closer to the upper primary tone by the remaining *O*s. An increase in the difference of the primary tones to 24 ~ brought the pitch of the intertone closer to the lower primary for all *O*s. Thus the pitch of the dominant tone of the beating complex decreased from a position nearer to the upper primary to a position nearer to the lower primary as the difference in the frequency of the primaries was increased. These findings are at variance with the views of *Myers* (14, pp. 37–38), *Kreuger* (10) and *Titchener* (24, p. 105) who hold that the pitch of the intertone rises when the difference in the frequencies of the primaries are increased.

As far as we are aware, no previous research has dealt with the effect of intensive changes on the quality of the beating complex. The results of the present study show that the quality of the beat is dependent both upon the relative and the absolute intensities of the primaries and indicate the necessity of controlling the intensities of the primaries when the effect of changes in the difference in frequency on the quality of the beat is studied.

A short series of experiments in which *O* was asked to compare the quality of the beating complex associated with frequency differences of 8, 16, 28 and 44 ~, showed that in an adequate study of the change in the quality of the beating complex as the difference in frequency of the primaries is increased neither audio-oscillators with the present types of available receivers nor Stern variators can be used as the source of the tones. Such a study requires that several sets of electrically driven tuning forks, whose frequencies differ in small steps, be available and that each set cover sections of the tonal range at intervals of an octave. Such an investigation is considered to be beyond the scope of the present study.

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APPARENT MOVEMENT IN AUDITORY PERCEPTION [1]

by

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Introduction. Studies of apparent movement, the perception of two stationary objects exposed in quick succession as a single object in motion, are numerous in the visual and tactual modalities, but surprisingly little searching work has been done on the subject in the auditory field. Perhaps this is because of the greater difficulties with physical and psychological controls in audition, and because the phenomenon seems to be more subtle and less stable in this field than in the others. Apparent auditory movement, however, occasionally intrudes itself into studies in sound localization. *Klemm* (13, p. 108) incidentally found such movement at the interval of approximately 5 σ between telephonic clicks; and in a later study (14, p. 129) some of his *O*s reported the phenomenon in the vicinity of the binaural temporal thresholds and below, *i.e.,* between 2 σ and .05 σ. *Trimble* (22, p. 222), working in localization with sounds from electric sparks, by means of what he calls "a single impulse technique", obtained reports of movement from some of his *O*s "when the temporal interval ranges above 9.48 σ + .98 σ". *Wittmann* (24) also discovered it with certain temporal relationships of sound, both when he worked with watch-ticks and with clicks from telephone receivers. In most of these cases of accidental discovery of the phenomenon, only as a rule do some of the *O*s hear it. Nor do all of the studies of similar nature, by any means, report it. We

[1] The writer expresses acknowledgments to Professor Christian A. Ruckmick, who suggested the problem and was in charge of the work; to Dean C. E. Seashore, who made suggestions; to Professor R. H. Wheeler, who criticized the manuscript; to the observers who gave so generously of their time; and to the department mechanic, Mr. J. B. Dempster, who made all of the switches used and suggested improvements in the wiring of the apparatus.

find no mention of it, *e.g.,* in *Starch* (20), in *Hamlin* (9), or in *Bennett* (2), all of whom worked with successive, brief auditory stimuli.

We are further familiar with apparent auditory movement from a number of studies which have been concerned with continous sounds and phase changes, *e.g.,* those of *Lane* (15), *Seashore* (19), *Halverson* (7, 8), *Wittmann* (24) and others. Under the condition of continuous sound the phenomenon seems to be more constant from *O* to *O*.

Three direct approaches have been made to the problem of apparent auditory movement with the particular aim of comparing it with the visual *phi*-phenomenon. The first was a preliminary study by *Burtt* (5) in 1917. He worked with more prolonged sounds than clicks, varying the exposure time from 33 σ to 225 σ, and the intervals between pairs of sounds from 6 σ to 100 σ. He investigated the following problems: (1) "The possibility of auditory illusions of movement." (p. 64); (2) "The relation between exposure and interval." (p. 64); (3) "The effect of difference in the intensity of the two stimuli." (p. 64). He concluded that:

1. "The presentation of two faint similar auditory stimuli in quick succession a few centimeters apart yields, under certain conditions, an impression of a sound moving in the direction of the actual temporal succession of the stimuli. Individuals vary in their susceptibility to the illusion but four of the five subjects used manifested it at various times." (p. 73).
2. "There appears a rather definite relation between the length of the period of exposure and of the interval between the stimuli. The longer the exposure, the relatively shorter must be the time interval to yield the optimal impression of movement." (p. 74).
3. "If the intensity of the second stimulus is greater than that of the first the apparent movement is often in the reverse direction." (p. 74).

These findings are similar to some of the earlier findings regarding visual *phi*-phenomena.

Kester (12), with a particular interest in configurational functions, made a somewhat more extended study of auditory phenomena of movement using telephonic clicks as stimuli. It seems to be the "pure" *phi*-phenomenon which he found—a movement without something which moves. "Niemand verfiel hier auf den Gedanken, ja es wurde als absurd abgelehnt, zu sagen, der Schall

(wie im Optischen der Lichtpunkt) habe sich von *a* nach *b* bewegt; auch kein 'Etwas' bewegt sich; die Zeit zwischen den beiden Knacken ist auch nicht mit Schallempfindung ausgefüllt; mit einem Wort, es bildet sich bei günstiger Pause zwischen den beiden Schallen das Wertheimersche 'reine ϕ-phänomen' heraus." (p. 106). His receivers, he says, were not well equated, and *E* and *O* worked in the same room. These conditions he deplored but was unable to rectify for practical reasons. It is not possible, from his report, to tell exactly what his further conditions were. He worked with the receivers separated by 1, 2, 3, and 4 m., and with *O* 1 m. from them, but results are not reported for each specific condition. His conclusions appear to apply to all of them.

1. All except one of 15 *O*s experienced the movement. (*Cf.* p. 105).
2. Although the untrained *O*s did not use the term "movement" spontaneously they did experience the movement beginning at the interval of about 140 σ and lasting to the interval of about 800 σ with qualitative changes varying with the time.
   a) At 140 σ the sound "shoots" in a straight line from sound source one to sound source two. (*Cf.* p. 106).
   b) With a lengthening of the interval the movement became slower, more pleasant, "softer", "lazier" and "bowed", until finally, at about 800 σ, there was a break in the "bow", and pure succession occurred. (*Cf.* pp. 106–7).
3. Rhythmical exposures favored movement. (*Cf.* p. 107).
4. *Korte's* laws regarding the relations between interval, distance and intensity for apparent visual movement were tested but not verified. Results were most favorable to the third law, which states that optimal distance is directly proportional to the temporal interval. (*Cf.* p. 108).
5. *Wertheimer's* pure *phi, i.e.,* movement without something which moves, was found. (*Cf.* p. 108).

In the earlier part of his study which was concerned with the localization of sound, *Kester* had been interested in what he called the *abstandes Verkurzung* tendency, and the functional relation between temporal interval and phenomenal space, a particularly fertile approach for the support of a configurational theory. No report of this tendency is made in connection with the experiments for movement in which he worked with two clicks, but he found it very conspicuously present when he later worked with clicks from three receivers which were equally spaced but which clicked with a different temporal interval between the terminal and intermediate clicks. Again his results were not reported in full.

The third study was made by *Scholz* (17) who used " sound hammers " which were separated at different times by 100, 30 and 15 cm. on a line the center of which lay in the median plane of the *O*s and one meter from them. Usually phenomenal simultaneity occurred with temporal intervals shorter than 50 σ (an extraordinarily large interval!). With the separation of 100 cm. between the sources of sound one *O* reported some kind of movement at all of the temporal intervals from 56 σ through 245 σ (p. 250); with a separation of 30 cm. another *O* reported movement at all temporal intervals from 210 σ through 490 σ (p. 254); and with a separation of 15 cm. another *O* also reported movement at all temporal intervals from 175 σ through 490 σ (p. 256). Whether the three *O*s agreed in their reports under each of the conditions is not clear from *Scholz's* report. The movement, however, was not often acoustically *anschaulich* throughout its entire course (p. 250), though sometimes the sound itself seemed to move across the entire distance. With the " sound hammers " separated by 100 cm. he found a close correspondence between the range of movement and the range of greatest phenomenal shortening of distance between the sounds (p. 252), a less close relationship with a separation of 30 cm. (p. 254), and a negative relationship with a separation of 15 cm. (p. 257). *Scholz* attempted also to study the effect of different intensities upon apparent movement, but was dissatisfied with his results because of the large differences in quality which accompanied the differences in intensity.

Problem. In the foregoing studies we find widely different results, and also differences in the conditions of experimentation. *Burtt* worked with relatively long exposure times. The receivers were placed 1 m. apart. Sometimes his *O*s were seated halfway between the receivers and sometimes at a distance of 2 m. from them. Most of the *O*s who served in the studies made by *Kester* and *Scholz* were familiar with the visual *phi*-phenomenon and many of them knew the purpose of the experiments. Some of those who did not know the purpose did not describe what they heard as movement until the word was suggested to them. *Kester*

appears to describe only the "pure" *phi*-phenomenon, whereas *Scholz* describes also a *moving sound.* The position of *Kester's Os* with reference to the receivers is not reported in relation to specific data. The stimuli differ somewhat in the several studies and the temporal intervals which were found by the different investigators to favor movement range from .05 σ, according to *Klemm,* to 800 σ, according to *Kester.*

In view of these facts the need for finding reliable conditions for the arousal of this phenomenon becomes obvious. It was in the interest of finding and describing compulsory conditions for apparent auditory movement with the presentation of pairs of very brief stimuli that this study was made.

Apparatus. The apparatus consisted of two main units, the timing and click-producing apparatus, and the signalling and reporting unit, besides a number of accessory parts.

For the timing apparatus a small double spring Victrola motor, type VV–VI, was chosen as readily adaptable to the wide range of exposure times and intervals between exposures which we had hoped to employ. This machine was carefully calibrated and it was found that in normal room temperature, with a speed of 85 r.p.m., it ran accurately within a very small part of a σ throughout most of its range.

The Victrola was then equipped with two spring switches of heavy copper lined with silver plates, each of which controlled the circuit of a single telephone receiver (Fig. 1, S_1 and S_2). These switches were opened and closed by star wheels of six points each, and they were in turn actuated by two pegs protruding from the edges of the turntable. Each time a peg passed the switch the star wheel was given one-sixth of a turn so that it either opened or closed the switch (Fig. 2). Throughout our experiments these pegs were so placed as to bisect the circumference of the turntable; they could, of course, be otherwise placed upon the circumference according to the temporal intervals desired.

One of the star contact switches was stationary, the other was mounted on a movable arm. When the switches were placed at 180° from each other the clicks were simultaneous. From that point, which was marked as zero on a calibrated scale placed on the framework under the turn table, the movable switch could be set so that the temporal interval varied from 0 σ to 320 σ, the

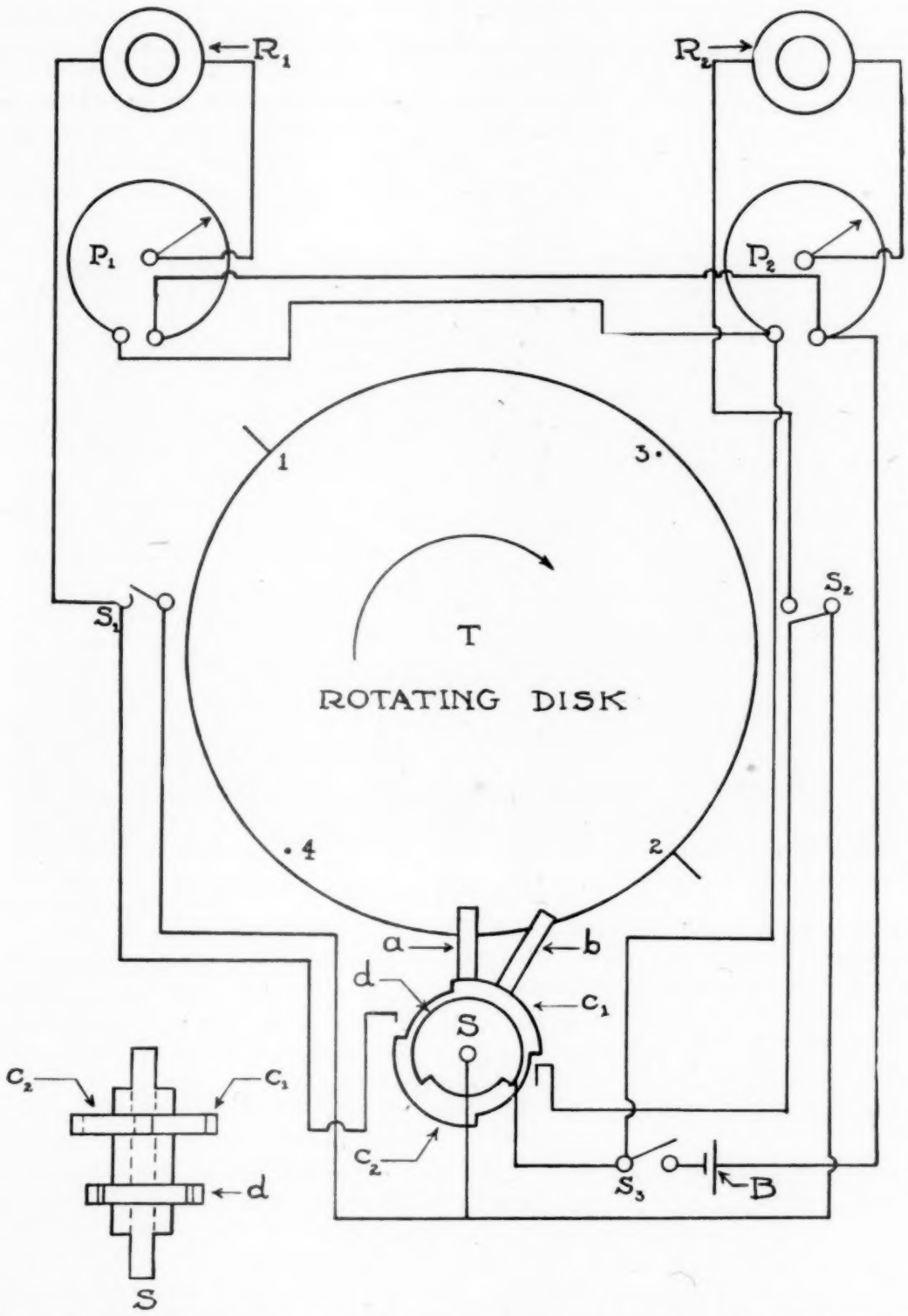

FIG. 1. Wiring of apparatus with potentiometers in circuit and schematic drawing of triple switch

S—triple switch showing C_1 and C_2 open
C_1 and C_2—switches controlling short circuit across S_1 and S_2
d—automatic switch disconnecting apparatus from battery
a—arm of C_1 and C_2
b—arm of d
S_1 and S_2—star contact switches
S_3—hand switch to disconnect apparatus from battery
1 and 2—pegs controlling S_1 and S_2
3 and 4—pegs controlling a and b
R_1 and R_2—receivers

extent of the range used in this experiment. The apparatus could easily be adapted to larger intervals.

Such an arrangement by itself, however, would cause rapid, rhythmical make and break clicks in the receivers. In order to produce only the two desired break clicks, one in each receiver, a triple switch arrangement (Figs. 1 and 2) was mounted on a movable arm (Fig. 2) which could be advanced to a point

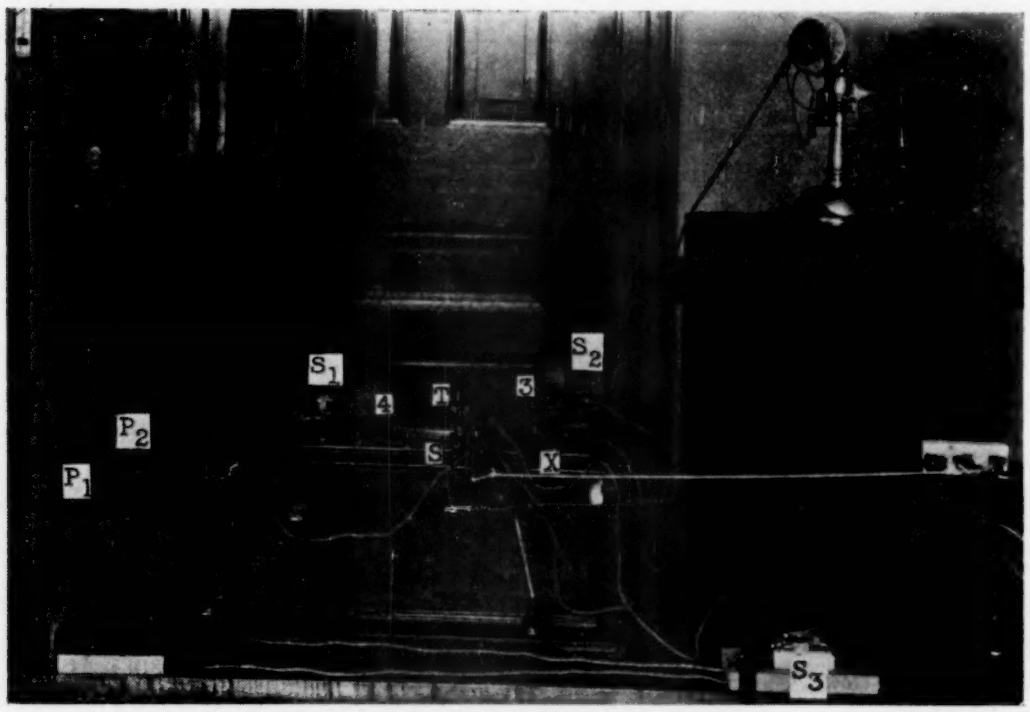

FIG. 2. Timing apparatus and resistances

P_1 and P_2—potentiometers
S—triple switch
S_1 and S_2—star contact switches
S_3—hand switch
T—turntable
X—adjustable arm carrying triple switch
2—one of pegs controlling star contact switches
3 and 4—upright pegs controlling —S—

near the edge of the turn table, and could be withdrawn by the hand of *E*. When the triple switch was closed the receivers were short circuited so that no clicks occurred regardless of the action of the star contact switches. When, however, switches C_1 and C_2 were opened there was no short circuit and the star switches were operative. Switches C_1, C_2 and d were automatically opened, after arm X had been pushed into position, by insulated pegs placed upright in the turntable. Peg 3, the taller one, opened switches C_1 and C_2, and peg 4 opened switch d. These pegs were placed midway between pegs 1 and 2 on the apparatus; the requirement was that they be so placed that peg 3 opened switches C_1 and C_2 after pegs 1 and 2 had closed switches 1 and 2 and just before they again opened them; and that peg 4 next opened switch d, thus disconnecting the total apparatus from the battery, before pegs 1 and 2 had again closed switches 1 and 2. This arrangement made it possible, by

proper setting of the five switches and adjustment of arm X, to let the turntable acquire full speed before the clicks were produced and to limit the clicks to the two desired. Switches 1 and 2 required to be adjusted only at the beginning of the experimental hour; switches C_1, C_2 and d had to be adjusted for each exposure, but since they were all mounted on the same axis one turn of the upright adjusted all of them, an operation that was very quickly and easily accomplished. The contacts in all of these switches were of sterling silver, and were made tight by springs of tempered steel or copper. They were polished on every day of experimentation. In addition to the switches already mentioned there was a hand switch, S_3, clamped to the apparatus table which was used to disconnect the apparatus from the battery while switches C_1 and C_2 and d were being adjusted so that the *O*s should not hear the series of clicks that would otherwise be produced by the adjustment.

The clicks were made by breaking the current flowing through two telephone receivers. We strove for a long time to find two sources of noise which would emit perceptually like noises since *Kester* (**12**) had deplored his own technique with unmatched receivers, and since it seemed reasonable to suppose that the effect of movement would occur more easily under such conditions. Buzzers, ivory balls, and other types of receivers were finally discarded in favor of a pair of receivers, No. 552 W, procured from the Bell Telephone Laboratories. Those receivers have a high electrical resistance, are carefully matched for physical intensity, and are highly damped and designed to have practically uniform response over a wide range of frequency. This does not mean, however, that the clicks produced by the separate receivers were qualitatively alike, nor should we, perhaps, expect to find two noises from separate sources so equated.[2] But it does mean that they were so nearly alike that the *O*s sometimes could note no difference between them, and that they were at the time perhaps the most "standard" noises available for other experiments as well as our own—a point which we feel is of considerable importance in a field of research in which procedures and findings in different laboratories have been as discrepant as they have been in this one.

These receivers were placed in a soundproof room which measured approximately 12 x 12 x 12 feet (*cf.* **16**, pp. 142–143). They were mounted in various positions as the procedures of the different series demanded (to be later described). In the early work of the experiment they were wired directly into the current of a 1.1 v. (closed circuit) Edison cell regardless of the polarity of their respective magnetic fields. Later a pair of 200 ohm General Radio potentiometers (Type 301) were added to reduce the intensity of the sounds. With these potentiometers set at zero, the current which went through the receivers was .01 amps. at .6 v. The complete wiring of this system is shown in Fig. 1. The position of the Edison cell in the circuit is important since a faint click was produced by the opening of switches C_1 and C_2 when the battery was placed on the other side of the potentiometers, or nearer the receivers. Still later in the experiments when greater intensity was desired and a 22.5 v. radio "B" battery was added to the Edison cell, greater resistance was needed to reduce the current, and the potentiometers

[2] Even after a great deal of adjustment of various kinds of apparatus tested we were unable to find any two noises from different sources which, from the psychological point of view, we could designate as qualitatively equal. And physicists, so far as we were able to learn, could not direct us to any which were physically equal.

were replaced by rheostats of constantine wire with which, together with the receivers' own resistance, we held the current which went through the receivers at .1 amp.

A telephone system on a separate circuit with buzzers and light signals constituted the second unit of the apparatus.

In the course of the experiments a guide for localization was added. This consisted of two arcs, one horizontal and one vertical, bearing scales marked in degrees with radium paint on a black background. The horizontal arc was a semi-circle, 115 cm. in diameter; the vertical arc of 135° bisected the horizontal arc at the zero point. These arcs supported by a transverse arc were mounted on tripods and placed before *O* in the observation chair. Figures, 15 mm. high, of grade L " Undark " were easily legible in the dark at 60 cm., the approximate distance of the arc from *O's* eyes.[3]

In one of the series biting boards were used. These were made, one for each *O*, with a dental impression compound on thin wooden boards which were clamped into place on the observation chair after *O* was seated.

In Series XI the *Seashore* sound perimeter (18) was used to support the receivers.

Observers. Twenty *O*s, seven trained and thirteen relatively untrained, served in the study. The trained *O*s were selected only after we had found by audiometric tests that their acuity was the same in both ears.

B, C, D and I were graduate students in the department of psychology. D had already observed in auditory experiments for a period of two years after he had completed the advanced course in experimental psychology. B, C and I had had one year of similar experience. A was an undergraduate student with two years of training in observing. G, X, Y, and Z were just beginning the course in laboratory psychology and had had little or no training in audition. The others, E, F, J, K, L, M, N, P, Q, R and S, had had, or were then taking, the course in elementary psychology. Eight of the 20 *O*s were women. *E*, of this study, observed regularly twice a week in the interest of planning new series and of controlling those in progress. *E*'s observations, however, are not reported since the conditions and procedures under which she observed were necessarily more varied and irregular than they were for the other *O*s, and she worked with full knowledge of the conditions.

[3] A brief description of this technique appeared in the *Amer. J. Psychol.*, 42, 1930, 638.

General conditions and procedure. All of the observations were made in the soundproof room. The walls of the room were lined with broadcloth, the floor was covered with linoleum, and there were two large tables and other smaller reflecting surfaces in the room. The *O*s sat in a chair of standard height and the receivers were adjusted to the plane of the ears of each *O* (except in Series I in which the receivers were placed vertically in the median plane, and there the mid-point between the receivers was on a horizontal level with the ears).

To check the exact angular distance of *O* from the receivers the clicks were simultaneously produced by breaking the current at S_3. Five reports of median localization were taken as evidence that adjustments were the same for the different observational hours. These tests and adjustments were made each day for each individual *O*. In all of the series except Series I and II the zero point on the arc for localization served as a point of fixation.

The control apparatus and *E* were stationed in an adjoining room so that there was a "background" of silence for the clicks. Communication between *E* and *O* was made through the telephone system. In addition *E* could signal *O* by means of faint lights (4 v. bulbs), and *O* could signal *E* with a buzzer.

The trained *O*s, who served through periods of one to two years, were kept ignorant at all times of the experimental "set-up" and of the purpose of the problem. This was true also for the untrained *O*s except in the series where the procedure necessitated a knowledge of the position of the receivers. The soundproof room was dark when the *O*s entered it, and the additional precaution was taken of drawing a black curtain between the receivers and *O*'s chair before he entered the room. A few minutes were allowed for dark adaptation to enable *O* to read the luminous figures on the arcs for localization. In those series in which *O*'s back was turned to the receivers this period was shortened to 15 to 30 sec. by turning on the electric light for that period of time and increasing brilliancy of the radium figures by "flash". The horizontal arc of the calibrated scale was adjusted to the height of the receivers. In the first series the signal for *O* was a buzzer, but the sound was startling in the stillness of the room and was later changed to a small 4 v. light placed directly in front of *O*.

Single observation periods in general lasted 50 minutes, but this period was broken in the middle by a rest period of 5 or 10 min. During this rest period and at the beginning of the hour the room was ventilated by means of a large electric fan. These precautions were considered important since *O*s frequently reported the work as very fatiguing.

The telephone was placed either on a shelf near *O* or in *O*'s hand. At the light signal he took his potition for attention; a few seconds afterwards he heard the sound or sounds; and

immediately after that he reported by telephone what he had heard. The number of observations reported in an hour varied from 20 to 50, the exact number depending upon the fullness of the descriptions.

The maximum range of any of the series was from 0 σ to 320 σ. This upper limit was determined by the results of earlier studies and of our own. To some extent the results also determined the size of the steps in the series. The steps were always in intervals of 1, 5, 10 or 20 σ. In all of the experiments except in Series X we used ascending series, and in some included also descending series. The ascending series were given the preference because we believed they would favor phenomena of movement more than the descending series would, since in a descending series the longer temporal intervals in the first trials would tend to give the *O*s a set for "two-ness." In so far as it was possible, however, we conducted both ascending and descending series in those experiments in which results were positive. The more exact description of our different series will be given later.

Experimental series. We planned our first experiment to fit the hypothesis that apparent movement would occur most readily under conditions in which localization was least definite. There was some support for this hypothesis in the results of *Burtt* (5) and *Scholz* (17), and in *Benussi's* (4) contention that illusions arise from an "inadequacy process." In our first experiment we therefore placed the sources of sound in the median plane of *O* where localization is ordinarily relatively uncertain and erroneous. It proved to be too difficult, however, and in the next group of experiments we tried to set up conditions which had produced positive results in earlier studies but, as far as possible, to keep the factor of suggestion under control.[4] The experiments did not always follow the order in which they are presented here. At times we conducted different series with the trained and untrained *O*s on the same days.

[4] By "suggestion" in this study we shall mean, unless otherwise indicated in the text, the influencing of *O*, by means of formal instructions or knowledge of the purpose and conditions of the experiments, to expect or vividly to imagine a given phenomenon.

A. Receivers vertically placed in the median plane

Series I

Procedure. The receivers were placed one directly above the other 1 m. apart on the median plane of *O* and one meter in front of him, making an angular distance of 50° between the receivers. This distance, we supposed, would be adequate since *Starch* (20, p. 38) reported an angular separation of 11° in the median plane sufficient to cause two clicks to be localized in different places. Receiver A was placed above receiver B and clicked first. The current which passed through the receivers was .01 amp. at .6 v. This produced a relatively faint click. We adopted it in the beginning because it helped to minimize the qualitative differences between the two receivers, and because *Kester* (12, p. 107) had reported that movement with loud clicks was very unpleasant. He failed, however, to report his intensities in physical terms, and we could only guess at them. *Burtt* (5, p. 71) also suggested the disadvantage of loud sounds.

We began with an ascending series with small steps in temporal intervals. We increased the intervals between the paired stimuli by 1 σ from 0 σ to 50 σ inclusive. These steps we later discovered to have been unnecessarily small. Then because individual differences were so large we made five trials for each *O* at 100 σ and five at 200 σ. Only the trained *O*s A, C and D served in this series, and they were entirely ignorant of the problem and of the conditions. Upon entering the soundproof room they were given the following instructions: "At the buzzer signal sit straight in your chair and hold your head in position to fixate a point directly in front of you. A few seconds after the signal an auditory stimulus will be presented, your perception of which you will be asked to describe."

The results. Table I reports only the data for every second sigma of separation and the averages of the trials for 100 σ and 200 σ since these are fairly representative of the others. A heard the clicks as two sounds at the interval of 4 σ, D at 8 σ, and C heard them as one fused sound at all intervals up to and including 100 σ. A and C always localized the two sounds of a pair in

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TABLE I. *Results of Series I (abridged) presenting number of sounds heard, localizations, and descriptions*

O: Interval in σ	A: No. of s	A: Localization in degrees S1	A: Localization in degrees S2	A: Description	C: No. of s	C: Localization in degrees S1	C: Localization in degrees S2	C: Description	D: No. of s	D: Localization in degrees S1	D: Localization in degrees S2	D: Description
0	1	20u m	— —	—	1	5d m	— —	—	1	0v +l	— —	—
2	1	20u m	— —	—	1	5d m	— —	—	1	0v 3l	— —	—
4	1	25u m	— —	—	1	0v 5r	— —	—	1	5d +r	— —	a spread-out s
6	2	30u m	30u m	—	1	5d 5r	— —	—	1	+d 5l	— —	*a spread-out s
8	2	30u m	30u m	—	1	5d m	— —	—	2	+d +r	+d m	a spread-out s
10	2	30u m	30u m	—	1	0v 10l	— —	—	2	+d m	— —	2 s connected by faint s
12	2	30u m	30u m	—	1	5d m	— —	—	2	0v +l	+d +r	vis. im. dumbbell
14	2	30u m	30u m	—	1	0v m	— —	—	2	0v +l	+d +l	vis. im. hour-glass
16	2	? ?	? ?	—	1	15d 5r	— —	—	2	0v m	+d m	*vis. im. dumbbell
18	2	15u m	15u m	—	1	25d 15r	— —	—	2	0v +r	+d m	—
20	2	15u m	15u m	—	1	0v 5r	— —	—	2	+d +r	+d +l	*vis. im. dumbbell
22	2	15u m	15u m	—	1	15d 5r	— —	—	2	+d +r	+d +l	vis. im. hour-glass
24	2	20u m	20u m	—	1	25d m	— —	—	2	0v +r	+d m	—
26	2	25u m	25u m	—	1	5d 5r	— —	—	2	0d m	++d m	*2 spread-out ss
28	2	40u m	40u m	—	1	15d m	— —	—	2	+u ++r	+d +r	vis. im. funnel
30	2	40u m	40u m	—	1	0v 5r	— —	—	2	+u ++r	+d +r	*s1 disappeared in s2
32	2	40u m	40u m	—	1	0v 15r	— —	—	2	0v +l	++d ++l	vis. im. hour-glass
34	2	40u m	40u m	—	1	5d m	— —	—	2	3u ++r	+d +r	*2 connected ss
36	2	40u m	40u m	—	1	0v 5r	— —	—	2	0v ++l	++d +l	*2 separate ss
38	2	40u m	40u m	—	1	0v 15r	— —	—	2	? ?	? ?	2 " ss
40	2	40u m	40u m	—	1	5d 15r	— —	—	2	+d +r	++d ++r	2 " ss
42	2	40u m	40u m	—	1	25d m	— —	—	2	0v +r	++d +r	2 " ss
44	2	40u m	40u m	—	1	0v m	— —	—	2	+d +r	++d +r	2 " ss
46	2	40u m	40u m	—	1	5d m	— —	—	2	+d +l	++d +r	2 " ss
48	2	40u m	40u m	—	1	0v 15r	— —	—	2	+d +1	30d +r	2 " ss
50	2	40u m	40u m	—	1	15d m	— —	—	2	+d m	++d +l	*2 " ss
100	2	30u m	30u m	—	1	25d 5r	— —	—	2	+d +l	60d +l	*2 " ss
200	2	30u m	30u m	—	2	30d 5r	30d 5r	—	2	40d m	50d +l	*2 " ss

Legend:

s=sound
ss=sounds
S1=1st sound presented and heard as 1st (also the localization of single sounds when only one was heard)
S2=2nd sound presented and heard as 2nd
im.=image
+l=" slightly " left when exact amount was not given
+r=" slightly " right " " " " " "
++=more than " slightly "
u=above horizontal plane of ears
d=below horizontal plane of ears
v=vertical
vis.=visual
*=see full report in discussion of table
—=no report
?=*O* too uncertain about localization to report

the same place, but A consistently heard them above the zero line and C below the line.[5] Obviously we should not expect to get reports of movement until or unless the sounds could be localized in two separate places. D, however, did hear them in two places from his "two-ness" limen on through the longer intervals. This *O* was indefinite in his reports of localizations, using the terms "slightly up" or "slightly down" more often than definite figures. At the interval of 4 σ he gave a report of "five down," at 49 σ a report of "25 down," and at 100 σ and 200 σ reports of "50 down" and "60 down." This suggests that the phenomenal distance may have increased gradually from 5° to 30° as the series progressed.

D was the only one who described the perceptions in addition to localizing the sounds. A few of his reports quoted in full will supplement the reports in the table.

6 σ. "I imagined it as a vertical line instead of horizontal. The first part of the sound seemed to start slightly higher up than where the second part ended."

16 σ. "The first was directly above the second. The visual image is still that of an extended dumbbell."

20 σ. "The first sound was less sharp and pointed than the second was. I had a visual image of a dumbbell with the first end very large and round and the other end more pointed."

26 σ. "I no longer have the same visual imagery. The first sound is a small point, then there is a gap and then a second funnel-shaped sound growing larger toward the end."

30 σ. "The first sound dragged along a little while before it disappeared in the second; that is, the point of minimal sound was not halfway but nearer the second sound."

34 σ. "I still hear two sounds connected by a thin sound."

36 σ. "I am going to call them two separate sounds. The first one did not last into the second one as it has previously."

50 σ. "The second sound lasted longer and was the more intense. The two sounds were distinctly separate; yet it isn't a clear-cut separateness. They are separate in the sense that one does not come out of the other—it has not the same quality."

100 σ. "I am unable to say just where the first sound ended; its ending was not sharp. I always visualize it as ending toward the second sound."

200 σ. "There is a distinct interval between the sounds."

He did not mention movement but the stationary filling was persistent though apparently largely visual. If the spatial visuali-

[5] Note here and in subsequent series in this study divergence from the findings of *Banister* (1, p. 298), who has had only one report from a normal observer of localization of sound below the line joining the ears.

zations and the phenomenal prolongations of the clicks had been synthesized the resultant would probably have been perception of movement.

The failure on the part of the other *O*s to report either movement or fillings, and the large discrepancy in reports of "two-ness" and of localization led us to turn from these particular conditions to others which we hoped would bring more uniform responses.

B. Receivers placed on the horizontal plane of the ears with O seated 1 m. from the mid-point and on the median line between them.

In this next group of experiments we sought to make conditions more favorable to movement by placing the receivers at varying distances away from the median plane. Since localization is more accurate off the median plane we should at least expect more uniform localizations on the part of the *O*s, and hence more uniform conditions for the occurrence of apparent movement. Furthermore, this more nearly approached the conditions under which the phenomenon had earlier been described. *Kester* (12) and *Scholz* (17) had both reported apparent movement when the sources of sound were placed 1 m. apart on the horizontal plane of the ears. *Kester* also reported it for 2, 3 and 4 m. of separation of the telephones, and *Scholz* for 30 and 15 cm. of separation of his "sound hammers." In the group of experiments next reported we therefore varied the distance between the sound sources keeping *O* equally distant from the mid-point between them. The influence of suggestion from *E* was also studied.

Series II

Procedure. The reports of qualitative and intensive differences between the sounds in the last series led us to install potentiometer controls in the circuit (see Fig. 1). Preliminary to Series II we conducted a series of tests to find perceptual equality of intensity. The clicks were presented in pairs with one second of temporal separation and the *O*s were asked to judge whether the second sound was louder, equal to or less loud

than the first. Receivers A and B were clicked first in random order. The most judgments of equality were obtained when the potentiometers were set so that .01 amp. at .6 v. passed through receiver A and .009 amp. at .55 v. passed through receiver B. Hence this setting was used in Series II.

The results of the first series had also emphasized the importance of the factor of localization, which *Scholz* had already pointed out. Accordingly, in this series the scale calibrated with radium paint (described in the section on apparatus) was added and was used in all of the remaining series.

The consistent "up" localizations of A and "down" localizations of C in Series I suggested the advisability of fixing *O*'s head in position. For this purpose the biting board was used in Series II. A light signal in the median plane of *O* replaced the buzzer of the earlier series.

The receivers were placed on the horizontal plane of the ears 1 m. apart, with the membranes of the receivers in frontal-parallel position to *O*. *O* sat facing the receivers, 1 m. from the mid-point and on the median line between them,[6] making an angular distance of approximately 50° between the receivers. Receiver A was on *O*'s left and sounded first.

Trained *O*s A, B, C, D and I served in this experiment. The instructions were the same as in Series I except that the first sentence was changed to read, "At the light signal take your position in the biting board." The series progressed by regularly increasing steps of 5 σ from 0 σ to 320 σ. With D and I, who reported some apparent filling of sound, repetitions of the early parts of the series were made so that there was a total of 600 observations.

The results. The descriptions given by the *O*s in this and succeeding series fall into several classes. The following abbreviations will be used in subsequent tables to represent these descriptions. Unless otherwise indicated movement always progressed from right to left—from the position of the first click

[6] Hereafter in this report this distance between *O* and the mid-point between the receivers will be designated as d.

to or toward the position of the second. In the case of two discrete sounds, unless otherwise indicated, *O* heard first one sound on the right, then one on the left.

1. ho f m = homogeneous full movement. The click itself moved the full distance between the terminals.
2. ho i m = homogeneous initial movement. The first click moved toward the position of the second before it vanished. Then there was an empty interval of space and time before the second click occurred.
3. ho e m = homogeneous end movement. The first click sounded; then there was empty time and space before the second one sounded. The second click moved a few degrees further away from the first click to its own final position.
4. ho s f = homogeneous stationary filling. Same as 1 but without movement.
5. ho i s f = homogeneous initial stationary filling. Same as 2 without movement.
6. ho e s f = homogeneous end stationary filling. Same as 3 without movement.
7. he f m = heterogeneous full movement. A sound of different quality from that of the click moved the full distance between the terminal clicks.
8. he i m = heterogeneous initial movement. Same as 2 except that the sound which moved had a quality different from that of the click.
9. he e m = heterogeneous end movement. Same as 3 except that the sound which moved had a quality different from that of the click.
10. he s f = heterogeneous stationary filling. Same as 7 without movement.
11. he i f = heterogeneous initial filling. Same as 8 without movement.
12. he e f = heterogeneous end filling. Same as 9 without movement.
13. i f m = imaginal full movement. There was movement across the full distance between the terminal clicks but the *O* reported the movement as imaginal, usually in terms of visual or kinæsthetic imagery, or of a "feeling".
14. i i m = imaginal initial movement. Same as 2 except that the movement was reported in terms of imagery (as in 13).
15. i e m = imaginal end movement. Same as 3 except that the movement was reported in terms of imagery (as in 13).
16. i s f = imaginal stationary filling. Same as 4 except that the filling was reported in terms of imagery (as in 13).
17. i i s f = imaginal initial stationary filling.
18. i e s f = imaginal end stationary filling.
19. 2 s = two discrete sounds.
20. ..... = no report.
21. ..... = no presentation of stimulus.

Fig. 3 and Table II report the results for Series II. The individual differences were too great to average the results of all *O*s.

Some of the steps that were presented to *O*s in the series have been omitted in the figure since such abridgment does not fundamentally alter the picture. The table gives the full report. All descriptions beyond those of mere localization and the reporting of two separate sounds are given in the supplement to Table II. Three characteristics in the results are unmistakable. First, there is a sudden increase in phenomenal distance, then a decrease, and later another increase. The steep rise in the curves between 0 and 5 σ we should expect from what we have learned from the studies in sound localization. In addition to this there occurs

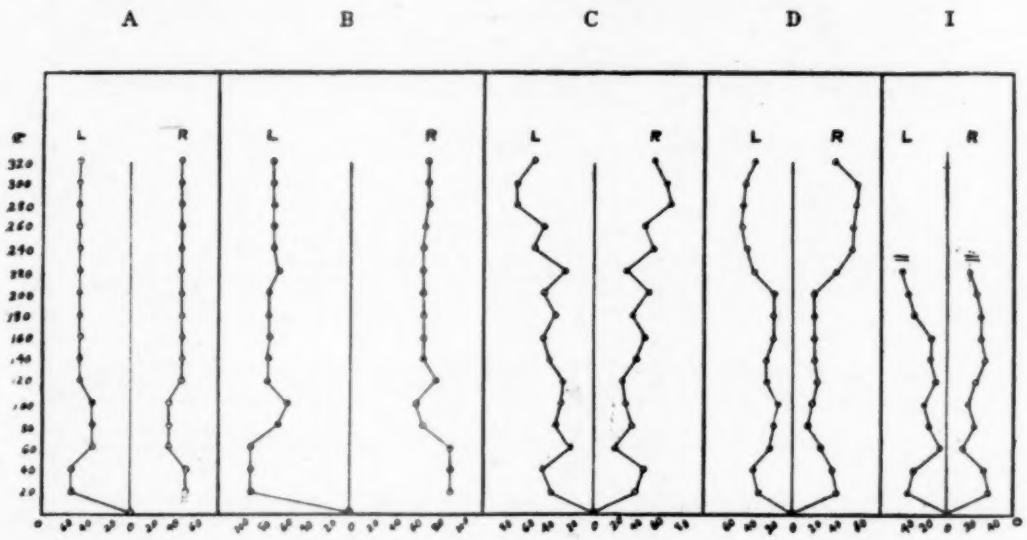

FIG. 3. Localization graphs for each *O* in Series II

at 50 σ to 60 σ an unmistakable tendency for the phenomenal distance between the sounds to shorten. It is impossible with our sources of complex sound to determine whether this is a result of different phase relationships. If it were we should have expected to find the effect repeating itself further along in our series. This it did not do. But that problem could only be accurately investigated with pure tones. *Kester* (12, pp. 81, 87) describes a similar happening, and *Scholz* (17, pp. 250, 254, 256) reports a shortening tendency for three different distances between the sources of sound. The ranges, within which the shortening occurs, however, differ. *Kester* (12) states as a general rule that the amount of phenomenal shortening increases with decrease in temporal interval. Our data for this series do

TABLE II. *Results of Series II presenting L and R localizations, total phenomenal distance between sounds, and descriptions*

O:	D				C				B				A				I			
Interval in σ	Localization in ° L	R	Total	Description	Localization in ° L	R	Total	Description	Localization in ° L	R	Total	Description	Localization in ° L	R	Total	Description	Localization in ° L	R	Total	Description
0	0	0	0	—	0	0	0	—	0	0	0	—	0	0	0	—	0	0	0	—
5	38	35	73	*ho s f	30	30	60	2 s	75	—	0	—	45	—	0	—	40	40	80	*ho s f
10	33	25	58	2 s	30	35	65	2 s	90	—	0	—	53	60	113	2 s	35	42	77	*ho f m
15	31	41	72	2 s	33	38	71	2 s	90	—	0	—	53	60	113	2 s	35	38	73	2 s
20	31	40	71	2 s	38	38	76	2 s	90	90	180	2 s	53	50	103	2 s	35	37	72	2 s
25	29	38	67	2 s	38	38	76	2 s	90	90	180	2 s	53	50	103	2 s	32	32	64	2 s
30	33	34	67	2 s	48	48	96	2 s	90	90	180	2 s	50	53	103	2 s	32	32	64	2 s
35	50	37	87	2 s	43	43	86	2 s	90	90	180	2 s	50	53	103	2 s	35	35	70	2 s
40	33	37	70	2 s	45	45	90	2 s	90	90	180	2 s	53	50	103	2 s	30	35	65	2 s
45	40	37	77	*he s f	43	43	86	2 s	90	90	180	2 s	50	45	95	2 s	30	35	65	2 s
50	33	37	70	2 s	35	35	70	2 s	90	90	180	2 s	48	43	91	2 s	33	37	70	2 s
55	12	10	22	2 s	20	20	40	2 s	90	90	180	2 s	35	35	70	2 s	10	20	30	2 s
60	20	24	44	2 s	20	20	40	2 s	90	90	180	2 s	35	35	70	2 s	5	15	20	2 s
65	12	20	32	2 s	15	35	50	2 s	65	65	130	2 s	35	35	70	2 s	30	45	75	2 s
70	20	17	37	2 s	30	30	60	2 s	65	65	130	2 s	35	35	70	2 s	30	30	60	2 s
75	20	18	38	2 s	37	37	74	2 s	65	65	130	2 s	35	35	70	2 s	15	25	40	2 s
80	17	13	30	2 s	35	35	70	2 s	65	65	130	2 s	35	35	70	2 s	15	25	40	2 s
85	20	18	38	2 s	15	15	30	2 s	60	60	120	2 s	35	35	70	2 s	15	20	35	2 s
90	11	14	25	*he s f	20	25	45	2 s	60	60	120	2 s	35	35	70	2 s	20	25	45	2 s
95	15	15	30	*he s f	25	25	50	2 s	60	60	120	2 s	35	35	70	2 s	45	15	60	2 s
100	12	17	29	*he s f	30	30	60	2 s	60	60	120	2 s	35	35	70	2 s	20	20	40	2 s
105	14	10	24	2 s	25	30	55	2 s	65	65	130	2 s	35	35	70	2 s	20	20	40	2 s
110	13	15	28	*he s f	20	34	54	2 s	65	65	130	2 s	35	35	70	2 s	20	20	40	2 s
115	12	14	26	*he s f	25	30	55	2 s	65	65	130	2 s	35	35	70	2 s	10	20	30	2 s
120	23	22	45	2 s	28	28	56	2 s	78	78	156	2 s	45	45	90	2 s	10	25	35	2 s
125	18	22	40	*he s f	23	25	48	2 s	78	78	156	2 s	45	45	90	2 s	25	35	60	2 s
130	15	19	34	*ho s f	35	33	68	2 s	78	78	156	2 s	45	45	90	2 s	25	35	60	2 s
135	17	15	32	2 s	30	30	60	2 s	65	65	130	2 s	45	45	90	2 s	25	35	60	2 s
140	23	20	43	2 s	40	40	80	2 s	75	65	140	2 s	45	45	90	2 s	15	35	50	2 s
145	17	15	32	2 s	40	50	90	2 s	75	65	140	2 s	45	45	90	2 s	30	35	65	2 s
150	16	17	33	2 s	40	45	85	2 s	75	65	140	2 s	45	45	90	2 s	20	30	50	2 s
155	18	17	35	2 s	45	45	90	2 s	75	65	140	2 s	45	45	90	2 s	35	20	55	2 s
160	17	20	37	2 s	45	45	90	2 s	75	65	140	2 s	45	45	90	2 s	15	30	45	2 s

Legend: * See full reports in Supplement following this table. See text for explanation of other symbols. In this series the first s was always on the left.

TABLE II. *Continued*

O:	D				C				B				A				I			
Interval in σ	Localization in ° L	R	Total	Description	Localization in ° L	R	Total	Description	Localization in ° L	R	Total	Description	Localization in ° L	R	Total	Description	Localization in ° L	R	Total	Description
165	15	12	27	2 s	45	45	90	2 s	75	65	140	2 s	45	45	90	2 s	15	30	45	2 s
170	20	20	40	2 s	50	50	100	2 s	75	65	140	2 s	45	45	90	2 s	15	30	45	2 s
175	20	17	37	2 s	55	45	100	2 s	75	65	140	2 s	45	45	90	2 s	30	30	60	2 s
180	18	20	38	2 s	35	35	70	2 s	75	65	140	2 s	45	45	90	2 s	30	30	60	2 s
185	16	20	36	2 s	45	45	90	2 s	75	65	140	2 s	45	45	90	2 s	30	30	60	2 s
190	21	17	38	2 s	35	35	70	2 s	75	65	140	2 s	45	45	90	2 s	30	30	60	2 s
195	22	20	42	2 s	45	45	90	2 s	75	65	140	2 s	45	45	90	2 s	30	30	60	2 s
200	18	20	38	2 s	45	45	90	2 s	75	65	140	2 s	45	45	90	2 s	35	25	60	2 s
205	16	17	33	2 s	50	50	100	2 s	75	45	120	2 s	45	45	90	2 s	40	20	60	2 s
210	18	20	38	2 s	40	40	80	2 s	75	45	120	2 s	45	45	90	2 s	40	20	60	2 s
215	15	20	35	2 s	25	30	55	2 s	65	65	130	2 s	45	45	90	2 s	40	20	60	2 s
220	33	39	72	2 s	25	30	55	2 s	65	65	130	2 s	45	45	90	2 s	40	20	60	2 s
225	36	41	77	2 s	35	35	70	2 s	65	65	130	2 s	45	45	90	2 s	40	20	60	2 s
230	45	48	93	2 s	58	63	121	2 s	65	65	130	2 s	45	45	90	2 s	40	20	60	2 s
235	50	43	93	2 s	45	48	93	2 s	65	65	130	2 s	45	45	90	2 s				
240	40	53	93	2 s	55	55	110	2 s	70	65	135	2 s	45	45	90	2 s				
245	45	55	100	2 s	58	60	118	2 s	70	65	135	2 s	45	45	90	2 s				
250	45	55	100	2 s	90	90	180	2 s	70	65	135	2 s	45	45	90	2 s				
255	50	45	95	2 s	55	55	110	2 s	70	65	135	2 s	45	45	90	2 s				
260	44	53	97	2 s	45	45	90	2 s	70	68	138	2 s	45	45	90	2 s				
265	35	45	80	2 s	55	55	110	2 s	70	68	138	2 s	45	45	90	2 s				
270	40	50	90	2 s	65	65	130	2 s	70	68	138	2 s	45	45	90	2 s				
275	43	58	101	2 s	55	55	110	2 s	70	68	138	2 s	45	45	90	2 s				
280	43	55	98	2 s	70	70	140	2 s	70	70	140	2 s	45	45	90	2 s				
285	43	60	103	2 s	55	55	110	2 s	70	70	140	2 s	45	45	90	2 s				
290	38	50	88	2 s	80	80	160	2 s	70	70	140	2 s	45	45	90	2 s				
295	43	55	98	2 s	50	50	100	2 s	70	70	140	2 s	45	45	90	2 s				
300	40	58	98	2 s	70	65	135	2 s	70	70	140	2 s	45	45	90	2 s				
305	43	50	93	2 s	65	65	130	2 s	70	70	140	2 s	45	45	90	2 s				
310	45	53	98	2 s	65	65	130	2 s	70	70	140	2 s	45	45	90	2 s				
315	38	53	91	2 s	55	55	110	2 s	70	70	140	2 s	45	45	90	2 s				
320	33	40	73	2 s	55	55	110	2 s	70	70	140	2 s	45	45	90	2 s				

SUPPLEMENT TO TABLE II

(Full reports for trials starred in Table II)

Observer D

5 σ. "There was sound spread along between the terminals."

45 σ. "The right one was the more intense, but somehow the left one lasted longer. Then, too, there was the effect of 'spread-out-ness' of some kind of sound between those two."

90 σ. "The second sound began slightly before the first had quit. And then there was more sound than just those two. I can't say where definitely except that it seemed to be spread out right in front of me; it seemed to come at the same time the others were occurring."

95 σ. "I was aware of additional very faint sound directly in front of me."

100, 110, 115 and 125 σ. "There was that effect of additional sound between the terminals. This sound has always a more spread-out effect than the others."

130 σ. "This time the additional sound seemed to be the first sound."

Observer I

5 σ. "The sound was all over the way from left to right."

10 σ. "The sound went somewhere but I couldn't follow it."

There were no other reports of movement nor of extended sound in Series II.

not support such a general statement, since between 50 σ and 5 σ our phenomenal distance was greater than it was between 0 σ and 5 σ, and between 50 σ and some considerably greater interval. Since *Kester* did not work with temporal intervals shorter than 40 σ we venture to say that his generalizations were perhaps prematurely drawn. The upper limit for this shortening effect was not so clearly shown; it varied from *O* to *O* and was usually not so clear-cut as its beginning. *Scholz* found that, with a similar setting of auditory stimuli (one meter apart) and with d equal to 120 cm., there was 100 per cent of shortening from 0 σ to approximately 50 σ, and then another range of shortening, though less in degree, between 75 σ and 175 σ. This region in his study corresponds to the region of reports of movement made by his two *O*s. Our curves for all five *O*s are considerably different from his, and we failed entirely, except for the one report by I, to get reports of movement under our conditions, although they were similar to his in temporal interval and spatial separation of stimuli.

We find only two *O*s, D and I, reporting anything but single (fused) sounds and two discrete sounds. I reported homo-

geneous filled space at 5 σ and 10 σ; D reported homogeneous filled space at 5 σ and heterogeneous filling in 32 per cent of the trials between 10 σ and 130 σ.

Series III

Procedure. Having failed again to get definite reports of movement we tried to establish still more favorable conditions for it.

The biting boards had been installed in the last series because the *O*s had expressed extreme dissatisfaction regarding their reports of localization, and because we realized that in the dark it was impossible for them always to take the same position at the "ready" signal. They still complained because of their uncertainty in the estimation of angles. Although localization of sounds was never stressed in the formal instructions, it became clear that the *O*s would inevitably localize. We decided, therefore, to make that task as easy for them as possible. Accordingly we installed the arc with the luminous figures (described in the section on apparatus) and used it in all of the remaining series. This served the further purpose of giving *O* a fixation spot at the zero point on the scale. It also raised the question of the necessity of the biting boards. Would they perhaps hinder more than they would aid in getting full descriptions? At best they put *O* in a unnatural posture, and the use of them perhaps unnecessarily suggested that the setting was one of localization. Under the conditions of Series II we tested A, C and D at various times with ten trials for each of the temporal intervals of 50 σ, 140 σ and 200 σ with and without biting boards. The results follow.

	With biting boards						Without biting boards					
	50 σ		140 σ		200 σ		50 σ		140 σ		200 σ	
O	Av.	AD.	Av.	AD.	Av.	AD.	Av.	AD.	Av.	AD.	Av.	AD.
A	80	10	88	3	91	2	85	12	89	2	89	2
C	67	10	81	10	95	5	67	10	82	9	92	5
D	72	4	41	5	39	4	73	2	40	5	39	4

From these results we concluded that the biting boards were an unnecessary inconvenience in our study, and accordingly we left them out in the remaining experiments.

If in Series I the situation had been too confusing then perhaps in Series II it was too clear. We saw no reason why we should not have had reports of movement under conditions so apparently similar to those under which *Kester* and *Scholz* had found it, unless it were that the mental set of our *O*s was unfavorable. *Titchener* (21, p. 358) pointed out that " . . . conscious predisposition (cortical set) is of great importance for the perception of movement, a fact which seriously complicates the problem set us by certain movement-illusions." Most of the *O*s in the studies of *Kester* and *Scholz* had observed apparent visual movement previous to their observations in the auditory study, and perhaps had a " set " to perceive auditory movement. Besides, in *Kester's* study many of the *O*s were informed of the purpose of the study. It might be argued that our *O*s who had been trained in an " atmosphere " requiring analytical descriptions of experiences centering around auditory localization were poor material for our experiment. *Benussi* (4) found that in vision *alpha* movement could be destroyed with an extreme analytical attitude, and *De Silva* (6, p. 499) also points to its importance in the visual field.

At this stage of our experimentation we were not willing, however, to sacrifice the naiveté (regarding the purpose of the study) of our regular *O*s. Hence we kept them as controls and brought in nine relatively untrained *O*s to work under instructions to observe movement. Series III and V, which follow, have then correlative Series IV and VI in which the physical conditions were kept respectively the same, but in which the psychological condition of " mental set " was different.

Kester reported that the perception of movement was favored if *O*'s back were turned to the receivers, and in Series III we adopted that condition. At the same time we placed the receivers 2 m. apart (making an angular distance of 90° between receivers), a position which *Kester* had found favorable, and increased the amount of current put through the receivers to .1 amp. at 24 v. This necessitated the substitution of the rheostats for the potentiometers. With the changed position of *O*,

TABLE III. *Results of Series III presenting averages of left and right localizations, total phenomenal distance between sounds, and descriptions*

O:	B				C				D				I			
	Localization in °				Localization in °				Localization in °				Localization in °			
Interval in σ	L	R	Total	Description	L	R	Total	Description	L	R	Total	Description	L	R	Total	Description
0	0	0	0	—	0	0	0	—	0	0	0	—	0	0	0	—
5	75	75	150	2 s	—	50	0	—	60	75	135	2 s	—	30	0	—
10	—	65	0	—	—	40	0	—	75	80	155	2 s	—	50	0	—
15	75	75	150	2 s	—	70	0	—	75	80	155	2 s	—	30	0	—
20	75	60	135	2 s	—	70	0	—	90	85	175	2 s	40	30	70	2 s
25	70	60	130	2 s	100	100	200	2 s	90	85	175	2 s	40	30	70	2 s
30	65	60	125	2 s	90	90	180	2 s	90	87	177	2 s	40	30	70	2 s
35	65	45	110	2 s	90	90	180	2 s	90	90	180	2 s	40	30	70	2 s
40	65	55	120	2 s	70	70	140	2 s	90	86	176	2 s	40	30	70	2 s
45	60	50	110	2 s	75	75	150	2 s	90	87	177	2 s	30	30	60	2 s
50	75	50	125	2 s	85	85	170	2 s	90	90	180	2 s	30	30	60	2 s
55	65	45	110	2 s	40	40	80	2 s	87	80	167	2 s	40	30	70	2 s
60	65	55	120	2 s	60	60	120	2 s	90	85	175	2 s	40	30	70	2 s
65	75	60	135	2 s	60	60	120	2 s	85	80	165	2 s	40	30	70	2 s
70	70	65	135	2 s	85	80	165	2 s	80	85	165	2 s	40	30	70	2 s
75	70	65	135	2 s	60	60	120	2 s	80	85	165	2 s	40	30	70	2 s
80	65	55	120	2 s	90	90	180	2 s	75	85	160	2 s	40	30	70	2 s
85	70	60	130	2 s	80	80	160	2 s	80	75	155	2 s	40	30	70	2 s
90	70	70	140	2 s	60	60	120	2 s	85	85	170	2 s	40	30	70	2 s
95	60	65	125	2 s	70	70	140	2 s	90	80	170	2 s	40	30	70	2 s
100	70	65	135	2 s	80	80	160	2 s	80	85	165	2 s	40	30	70	2 s
110	75	70	145	2 s	70	70	140	2 s	86	80	166	2 s	40	30	70	2 s
120	75	70	145	2 s	70	70	140	2 s	80	75	155	2 s	45	50	95	2 s
130	75	70	145	2 s	60	60	120	2 s	80	80	160	2 s	50	50	100	2 s
140	65	65	130	2 s	90	90	180	2 s	85	80	165	2 s	50	50	100	2 s
150	65	70	135	2 s	85	85	170	2 s	80	75	155	2 s	50	50	100	2 s
160	70	65	135	2 s	85	85	170	2 s	80	80	160	2 s	50	50	100	2 s
170	65	70	135	2 s	95	95	190	2 s	80	70	150	2 s	50	50	100	2 s
180	65	70	135	2 s	75	90	165	2 s	80	80	160	2 s	50	50	100	2 s
190	65	60	125	2 s	60	50	110	2 s	75	75	150	2 s	40	40	80	2 s
200	70	60	130	2 s	65	65	130	2 s	70	75	145	2 s	40	40	80	2 s
210	65	60	125	2 s	65	65	130	2 s	75	80	155	2 s	40	40	80	2 s
220	55	70	125	2 s	90	90	180	2 s	..	..	..	..	40	40	80	2 s
230	80	85	165	2 s	90	90	180	2 s	75	85	160	2 s	40	40	80	2 s
240	85	80	165	2 s	90	90	180	2 s	55	80	135	2 s	40	40	80	2 s
250	80	75	155	2 s	60	45	105	2 s	75	75	150	2 s	40	40	80	2 s
260	85	80	165	2 s	60	60	120	2 s	75	80	155	2 s	45	45	90	2 s
270	85	85	170	2 s	85	85	170	2 s	80	75	155	2 s	50	30	80	2 s
280	75	85	160	2 s	90	90	180	2 s	85	75	160	2 s	40	60	100	2 s
290	80	75	155	2 s	90	60	150	2 s	75	80	155	2 s	40	45	85	2 s
300	80	65	145	2 s	60	60	120	2 s	75	80	155	2 s	40	45	85	2 s
310	80	65	145	2 s	85	85	170	2 s	75	80	155	2 s	40	50	90	2 s
320	75	70	145	2 s	90	90	180	2 s	75	80	155	2 s	40	50	90	2 s

See text, p. 90, for explanation of symbols.

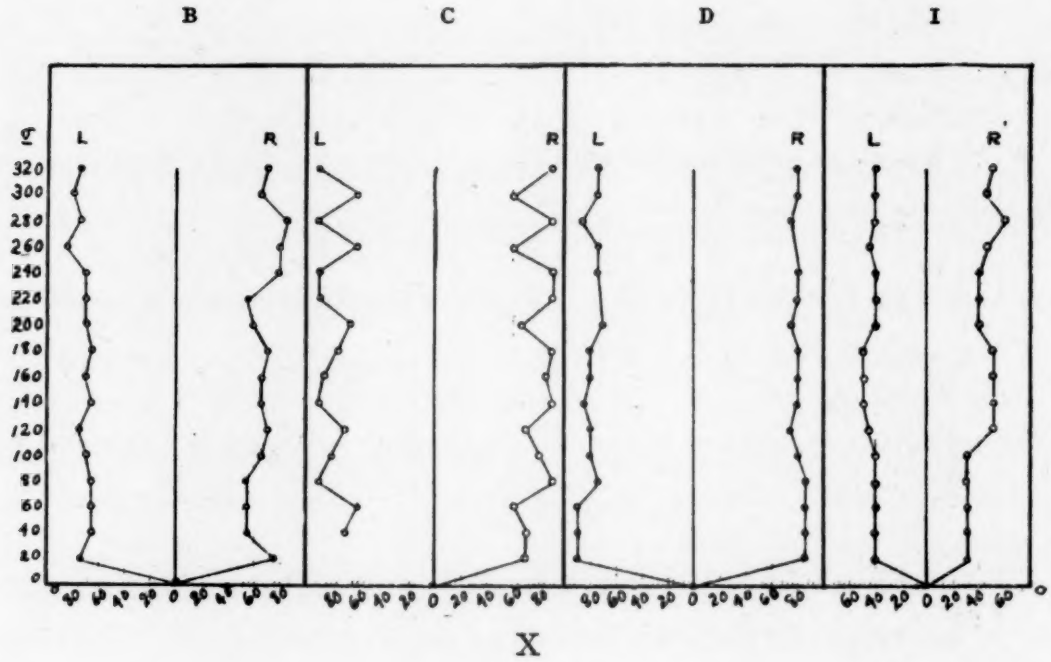

FIG. 4. Localization graphs for each *O* in Series III

X—horizontal localizations

Y—corresponding vertical localizations

O—horizontal plane on level of ears
U—above horizontal plane of ears
D—below horizontal plane of ears
dash line—sound on *O*'s right
dotted line—sound on *O*'s left

d remained the same, but receiver A was now on *O*'s right and sounded first.

Trained *O*s B, C, D and I served in this series. The instructions were the same as in Series I. In addition whenever *O* reported " overlapping " or " filling-in " he was asked to describe that as fully as possible. We conducted both ascending and descending series by steps of 5 σ between 0 σ and 100 σ, and by steps of 10 σ between 100 σ and 320 σ.

The results. Table III and Fig. 4 show the results for this series. The graphs show the results only by steps of 20 σ, but this abridgment does not alter the general outlines of the complete picture. We considered the individual differences too great to average the results of all the *O*s. The table shows that there were no reports of movement or of filling; there were only single (fused) sounds at the smaller intervals, or two discrete sounds at the larger values. The graphs show again the steep rise between 0 σ and 20 σ. The phenomenal distance between sounds is consistently less for I than for the other three *O*s, and C shows less stability in localizations from trial to trial than any of the others. But the tendency toward narrowing of the distance around the intervals of 50 σ is almost negligible in these trials.

In this series the *O*s quite consistently reported the vertical localizations of the sounds, no doubt because they were more variable than in the other series. This may have been a distracting factor. We tabulated them on the graphs to see if there were, perchance, a relationship between vertical and horizontal localizations. No generalizations can be made on this point beyond the statement that variability in horizontal localization from trial to trial is, in general, accompanied by variability in vertical localization.

Our results for this series were therefore entirely negative in regard to apparent movement.

Series IV

Procedure. Series IV is the correlate of Series III. The physical conditions were exactly the same in the two series but the *O*s and instructions were different. There were nine new

*O*s, J, K, L, M, N, P, Q, R and S, from the class in elementary psychology. Their instructions read as follows: "At the light signal sit straight in your chair and fixate the zero on the degree scale. A few seconds after the light signal you will hear a sound moving from right to left. Report where the movement starts at the right and where it ends at the left." The *O*s were especially cautioned not to discuss the experiment in any way with any of their friends lest their remarks influence the observations of the other *O*s. Reports were obtained for two complete series, one ascending and one descending by steps of 10 σ between 0 σ and 320 σ. At the end of these two series each *O* was asked to make general descriptive remarks. If the remarks included no comments about movement *O* was asked, " Will you describe the movement you heard?" Further specific questions which were sometimes asked are reported in connection with that *O*'s remarks.

The results. The individual localization graphs showed for these *O*s so much similarity that we thought it legitimate to

TABLE IV. *Average total phenomenal distance between sounds, and AD's of the average L and R localizations in Series IV*

Interval in σ	Av. total distance	AD L	AD R
0	0°	0°	0°
10	137	13	12
20	144	10	9
30	145	11	13
40	148	10	12
50	145	9	8
60	142	13	15
70	151	8	11
80	148	10	10
90	141	8	6
100	139	5	7
110	147	8	14
120	146	9	13
130	157	6	11
140	156	14	14
150	140	14	15
160	157	7	12
170	160	10	14
180	151	10	13
190	164	13	15
200	146	9	11
210	153	14	20
220	152	8	11
230	150	14	22
240	151	8	13
250	147	14	16
260	148	12	15
270	142	12	15
280	154	9	11
290	159	12	13
300	151	7	12
310	159	10	14
320	160	9	11

average them in Fig. 5. Table IV gives the AD's of the average left and right localizations shown in Fig. 5. The curves show the characteristic sudden rise between 0 σ and 10 σ. At 10 σ

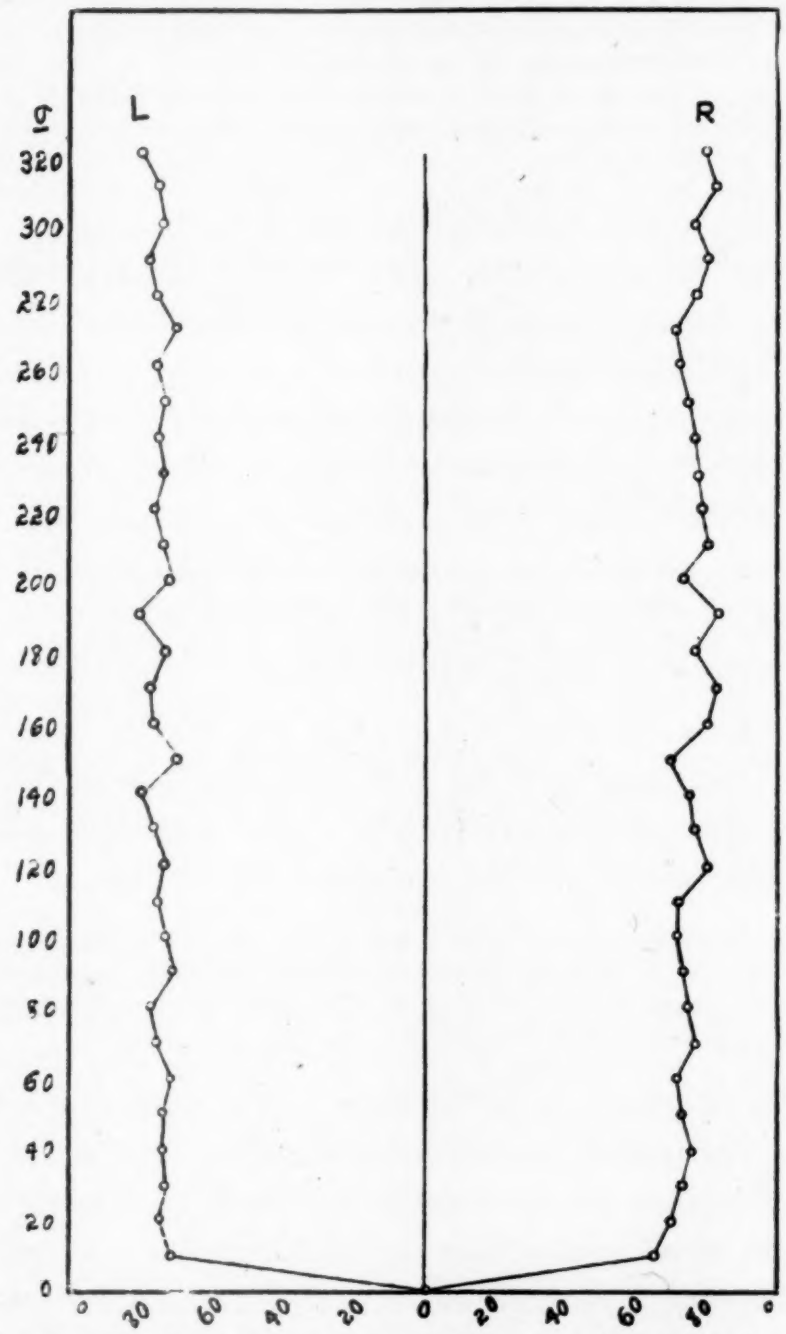

FIG. 5. Graph of average L and R localizations in Series IV

the curve has reached almost its maximal lateral displacement, and we find no other tendency, within our range, toward a shortening of the phenomenal distance between sounds.

Three *O*s, Q, S and K, reported movement or filled space. For

Q it was apparently constant throughout the series. When asked to describe the movement she said:

"It doesn't go directly straight across; it curves. It is easier to localize the sound at the right where it is more intense. You really don't hear it right back of you; then it gains in intensity again toward the left."

Question: "There definitely is sound moving across?"

"Yes, there is; you don't hear it behind you but you know it is there. I could hear a ring of sound, a faint hum that wasn't nearly so intense behind me as it was toward the sides."

It does not appear to have been the click that moved for this *O* but another kind of sound. This we have called heterogeneous movement. From the report we conclude that this *O* heard full, initial, and end movement.

S reported for small temporal values a "filling" of sound. The report does not indicate whether it was homogeneous or heterogeneous filling.

"There wasn't any movement to describe; I just got succession, one sound after the other. When the sounds were almost together in time it seemed more like movement but I still shouldn't call it exactly movement, though in those cases the time and space seemed to be filled."

K seemed less decided about what she heard. When asked to describe the movement she said, "It just seemed like a sort of snap or buzz halfway between." She was then asked, "Is there anything more you can say about the movement?"

Answer: "It always seems to be given in two very definite places. To me it does not seem as if it were two very separate, distinct and definite clicks. That was true except at the times when the clicks were very close together. Then I could just feel sound go from one place to the other."

It is difficult to tell from the report what kind this movement was, but it was probably what we have called imaginal movement in which the idea of movement is carried in some kind of imagery and the *O* is unwilling to call it *perception* of movement.

The other *O*s, J, L, M, N, P and R, heard no movement. Their responses to the request to describe movement are reported below.

J. "I can't describe it. There were just two separate sounds, entirely separate. There was no movement from one side to the other."

L. "There was never any impression of movement, even when the sounds were very close together in time."

M. "As far as I can tell there is no movement at all; it is just two distinct sounds. There is just one sound here and one sound there. When they are almost simultaneous the first one sounds louder. But there was no sense of movement even though I tried to get it."

N. "In most cases it was discernible which sound came first; in some the sounds were simultaneous. Sometimes the right sound is nearer the ear than the left one. I can only hear terminal sounds, I don't hear any moving. There were times when the two sounds were simultaneous or overlapping but I can't call that movement."

P. "There is a click on the right, and then just after it one on the left."

Question: "What was between them in time and space?"

"It seems like a split second—a time and space in which there is nothing."

R. "There is one click, and then right after it another one. There are two sounds without any movement between."

Q and K then were our first *O*s to report movement. Q's descriptions, though scanty, indicate that she heard the "bowed" movement which both *Kester* and *Scholz* reported. K's reports of movement seem to have referred only to the smaller temporal intervals where the clicks overlapped in time. What made the situation different for Q is not yet clear. Her curve of localization is less regular than most of the others, but no less so than that of L, who was very positive in his statement that there was never any movement.

But with only two of 13 *O*s reporting movement, we can not yet claim to have found a compulsory condition for it.

Series V

Procedure. Having failed to get reports of movement from our trained *O*s with the 2 m. and 1 m. separations of the receivers, we now placed them ½ m. apart leaving all other physical conditions and the instructions the same as in Series III. This made an angular distance of 30° between receivers.

The same trained *O*s, B, C, D and I, took part in this series. Because our *O*s were not to be available for more than a few more observation hours, and because we wanted to cover as many as possible of the conditions we had planned to investigate we shortened this series slightly by changing the length of the steps. In the light of the data earlier obtained we saw no objection to this since many of the reports for successive trials had been so similar that some of the different steps could have been

considered repetitions of the same interval. In Series V the steps progressed as follows:

By 5 σ between 0 σ and 100 σ.

By 10 σ between 100 σ and 140 σ.

By 20 σ between 140 σ and 320 σ.

C became ill and was unable to complete the series. D, who in this series began to report movement, was given repetitions of parts of the series between 0 σ and 120 σ and between 0 σ and 55 σ.

The results. Table V and Fig. 6 report the results in detail. The figures show that localization was somewhat less stable under this condition than it was under the others, and individual differences were again too great to justify combining results. The phenomenal distance between sounds is relatively small between 0 σ and 100 σ, and Table V shows at a glance that this region corresponds to the region of reports of movement given by D. Along with this fact it must be noted, however, that neither I, whose phenomenal distance was least of all, nor B, whose graph is very similar to D's, reported movement. This fact will be further discussed later. C and B reported a temporal, not spatial, overlapping of sound between 0 σ and 30 σ, and I reported some *imagery* of spatial filling between terminals between 30 σ and 50 σ. I reported at 50 σ:

"This overlapping bothers me; sometimes it seems to be only temporal, and sometimes spatial. Mostly they overlap only temporally and are point-sounds in space. Occasionally, there is some visual imagery of extent in space when they overlap."

The following types of reports from D have been translated into symbols in Table V. D's descriptions were usually clear and easy to interpret.

20 σ. "The space between the terminals was filled with the same sound, but I don't know whether the sound moved."

25 σ. "A line of the sound extended from the first to the second—from right to left."

35 σ. "The right sound moved four degrees toward the left before it vanished."

45 σ. "Sometimes I get the impression that the sound *moves* from the first to the second; sometimes it just *is* there without starting out from the first."

TABLE V. *Results of Series V presenting averages of left and right localization, total phenomenal distance between sounds, and schematic descriptions*

O:	I				B				C				D				D				D			
Interval in σ	Localization in ° L	R	Total	Description	Localization in ° L	R	Total	Description	Localization in ° L	R	Total	Description	Localization in ° L	R	Total	Description	Localization in ° L	R	Total	Description	Localization in ° L	R	Total	Description
0	0	0	0	—	0	0	0	—	0	0	0	—	0	0	0	—	0	0	0	—	0	0	0	—
5	0	0	0	2 s	3	3	6	2 s	—	35	0	—	0	9	9	2 s	0	0	0	—	—	3	0	—
10	0	0	0	—	3	3	6	2 s	—	10	0	—	−2	12	10	2 s	0	5	5	2 s	0	2	2	2 s
15	0	2	2	2 s	10	10	20	2 s	—	40	0	—	6	12	18	2 s	4	6	10	2 s	1	1	2	ho s f
20	3	3	6	2 s	10	13	23	2 s	0	0	0	—	9	15	24	*ho s f	5	5	10	ho i m	3	3	6	ho s f
25	0	3	3	2 s	10	10	20	2 s	—	15	0	—	6	9	15	*ho f m	5	3	8	2 s	4	3	7	2 s
30	8	8	16	i s f	15	15	30	2 s	15	15	30	2 s	6	6	12	2 s	5	4	9	2 s	4	5	9	ho e m
35	5	8	13	i s f	5	0	5	2 s	0	0	0	—	5	6	11	ho f m	0	5	5	ho s f	5	3	8	*ho i m
40	7	7	14	i s f	10	8	18	2 s	13	13	26	2 s	5	9	14	2 s	2	5	7	ho s f	4	5	9	ho f m
45	8	8	16	i s f	5	5	10	2 s	5	5	10	2 s	5	6	11	*ho s f	4	5	9	2 s	0	5	5	ho f m
50	8	8	16	i s f	13	8	21	2 s	10	10	20	2 s	5	4	9	*ho f m	2	4	6	2 s	2	2	4	2 s
55	4	4	8	2 s	5	20	25	2 s	15	15	30	2 s	10	5	15	*ho f m	3	4	7	ho i m				
60	6	6	12	2 s	8	5	13	2 s	18	18	36	2 s	20	14	34	2 s	4	7	11	ho i m				
65	5	5	10	2 s	5	0	5	2 s	15	15	30	2 s	10	10	20	ho f m	5	5	10	2 s				
70	7	7	14	2 s	13	13	26	2 s	5	5	10	2 s	10	7	17	2 s	5	5	10	ho f m				
75	5	5	10	2 s	5	20	25	2 s	7	7	14	2 s	13	14	27	he s f	7	10	17	ho i m				
80	8	8	16	2 s	13	15	28	2 s	10	10	20	2 s	12	12	24	ho f m	10	10	20	*ho e m				
85	9	9	18	2 s	5	20	25	2 s	15	15	30	2 s	15	15	30	2 s	7	9	16	2 s				
90	9	9	18	2 s	15	13	28	2 s	7	7	14	2 s	16	15	31	he s f	6	8	14	2 s				
95	9	9	18	2 s	15	15	30	2 s	15	5	20	2 s	20	20	40	2 s	15	10	25	ho i m				
100	9	9	18	2 s	10	25	35	2 s	5	5	10	2 s	20	17	37	2 s	10	10	20	ho i m				
110	9	9	18	2 s	25	0	25	2 s					12	15	27	ho s f	7	7	14	*ho i & e m				
120	8	8	16	2 s	20	5	25	2 s					25	22	47	2 s	15	14	29	2 s				
130	10	10	20	2 s	10	20	30	2 s					20	15	35	2 s								
140	8	8	16	2 s	10	10	20	2 s					20	15	35	2 s								
160	9	9	18	2 s	5	20	25	2 s					20	16	36	ho e m								
180	9	9	18	2 s	5	35	40	2 s					30	22	52	2 s								
200	9	9	18	2 s	15	25	40	2 s					12	10	22	2 s								
220	7	7	14	2 s	20	30	50	—					27	23	50	2 s								
240	7	7	14	2 s	20	30	50	2 s					20	15	35	2 s								
260	10	10	20	2 s	25	30	55	—					25	17	42	2 s								
280	10	10	20	2 s	25	30	55	2 s					20	13	33	2 s								
300	10	10	20	2 s	25	25	50	—					20	15	35	2 s								
320	10	10	20	2 s	30	40	70	2 s					25	22	47	2 s								

Legend: * See text for full reports. See text, p. 90, for explanation of other symbols.

50 σ and 55 σ. "It started out from the first and extended over to the second, but the puzzling part is that the quality of the sound between is that of the first sound so that it didn't seem so definitely to end in the second because the pitch of the second was higher."

80 σ. "The second sound started 3° right of its final location."

110 σ. "The first sound moved 3° toward the left and then vanished; the second sound started 3° right of its final localization."

120 σ. "Just two separate sounds."

Between 110 σ and 320 σ he made only one report of movement, and that was of homogeneous end movement at 160 σ.

We have now one *O* who has spontaneously reported homogeneous movement, and two who have reported heterogeneous and imaginal movement under suggestion. We wondered if

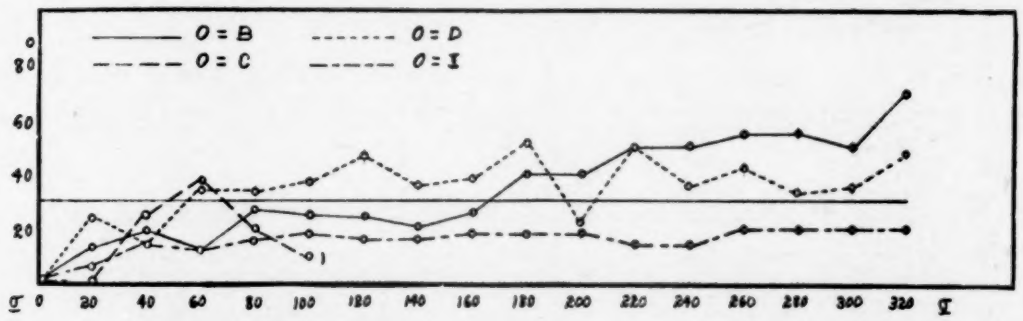

FIG. 6. Graphs of total phenomenal distance between terminal sounds for four *O*s in Series V
horizontal line at 30° = angular distance between receivers

D had guessed the purpose of the problem and was working under self-given instructions to observe movement. But some weeks later, at the end of his last observation hour, he said, in reply to questioning that he had never suspected that the study was one in apparent movement, nor that the movement he heard was illusory!

The distance between clicks for the *O*s computed from their localization of the clicks when they were sounded alone was for B 40°, for C 53°, for D 270° and for I 15°. For all of the *O*s some shortening of phenomenal distance is found for intervals below 80 σ; for C it extends throughout the range of the series, and for B it ends at 170 σ. There is some correspondence between the range of the *abstandes Verkurzung* and the range of reports of movement by D, but the correspondence is not close; and the two *O*s for whom that tendency manifested itself most strongly reported no movement.

Series VI

Procedure. Series VI repeated the physical conditions of Series V. The *O*s were the untrained *O*s who had just finished observing in Series IV. The procedure was changed from that in Series IV in two respects. The instructions were modified to read, "I have now arranged conditions so they are more favorable for movement; watch closely for the movement and describe it as fully as you can." The length of the series was not always under our control since some of the undergraduate *O*s were able to meet only a few appointments. The steps beyond the interval of 100 σ also varied, going by 10 σ for some *O*s and by 20 σ for others. We were obliged to choose between this variation in steps and stopping the series before 320 σ and we chose the former because we wanted to know whether the movement would extend to the limit of our range. Table VI reports the steps as they were given to each *O*. The figures for N and J represent averages of one ascending and one descending series; the others were given only one ascending series. At the end of each series each *O* was asked to elaborate further on his reports. Occasionally other questions were asked fitted to his own reports. These questions will be reported later together with their answers.

The results. Table VI gives the full reports of localization, total phenomenal distance reports and descriptions of movement for each interval presented to each *O*. Figs. 7a and 7b show the phenomenal distance for each *O* at every 20 σ in relation to the actual physical distance in degrees between the receivers.

In addition to these data the following descriptive reports are significant.

J. "There was movement in an imaginary way only. When the sounds come immediately after each other without a vacant interval of time I feel as though the sound travels. I don't know whether it is imaginative or not. I feel it in the body as though it shot straight across. There are always two clicks, but I feel as though the first travels to the position of the second and meets it. It isn't exactly the first click that travels; I picture it as a dim streak of light that goes across. It is more like imagination for that which moves is not like the click itself, not at all like it. The line is straight and the sounds are always a foot or more behind my head."

TABLE VI. *Results of Series VI presenting averages of left and right localizations, total phenomenal distance between sounds, and schematic descriptions*

O:	J				K				N				R				Q			
Interval in σ	Localization in ° L	R	Total	Description	Localization in ° L	R	Total	Description	Localization in ° L	R	Total	Description	Localization in ° L	R	Total	Description	Localization in ° L	R	Total	Description
0	0	0	0	—	0	0	0	—	0	0	0	—	0	0	0	—	0	0	0	—
5	0	15	0	—	5	5	10	*i f m	20	10	30	i s f	—	65	0	2 s	—	20	0	—
10	—	10	0	—	15	15	30	i f m	—	—	—	i s f	—	45	0	2 s	—	10	0	—
15	30	0	0	—	40	80	120	2 s	—	—	—	i f m	35	45	80	2 s	10	10	20	he s f
20	15	10	25	2 s	85	90	175	*i i m	—	—	—	i s f	25	30	55	2 s	5	20	25	2 s
25	15	20	35	i f m	60	45	105	*i f m	10	10	20	i s f	30	30	60	2 s	20	25	45	he s f
30	30	30	60	i f m	30	40	70	*i f m	10	20	30	i s f	40	40	80	2 s	20	25	45	he s f
35	15	25	40	i f m	10	10	20	*i f m	10	20	30	i s f	55	55	110	2 s	15	15	30	he s f
40	25	25	50	i f m	20	20	40	*i f m	10	20	30	i s f	50	50	100	2 s	15	20	35	he s f
45	10	30	40	i f m	30	15	45	i f m	10	20	30	i f m	40	40	80	2 s	25	25	50	he s f
50	25	30	55	i f m	20	20	40	i f m	20	30	50	i s f	30	30	60	2 s	25	30	55	he s f
55	60	45	105	i f m	20	15	35	i f m	10	20	30	i s f	40	40	80	2 s	25	25	50	he s f
60	90	75	165	i f m	10	10	20	i f m	10	20	30	i s f	45	45	90	2 s	20	20	40	he s f
65	60	90	150	i f m	15	10	25	2 s	..	..	..	..	45	45	90	2 s	30	30	60	he s f
70	60	45	105	i f m	10	10	20	i f m	10	10	20	he f m	45	45	90	2 s	40	35	75	he s f
75	30	20	50	i f m	15	15	30	2 s	..	..	..	..	60	60	120	2 s	50	45	95	he s f
80	45	30	75	i f m	5	10	15	2 s	5	20	25	he f m	70	70	140	2 s	30	30	60	he s f
85	20	10	30	i f m	10	10	20	i f m	..	..	..	..	75	75	150	2 s	35	30	65	he s f
90	60	45	105	i f m	10	15	25	2 s	20	20	40	he f m	75	75	150	2 s	20	20	40	he s f
95	45	40	85	i f m	20	15	35	i f m	..	..	..	..	60	60	120	2 s	45	50	95	he s f
100	45	30	75	i f m	15	10	25	2 s	10	20	30	he f m	70	70	140	2 s	20	20	40	he s f
110	15	10	25	i f m	20	15	35	i f m	..	..	..	..	..	..	..	..	..	..	..	..
120	15	10	25	i f m	15	10	25	i f m	10	20	30	he f m	70	70	140	2 s	25	30	55	he s f
130	45	50	95	i f m	10	15	25	i f m	..	..	..	..	..	..	..	..	..	..	..	..
140	45	35	80	i f m	15	10	25	i f m	10	20	30	he f m	70	70	140	2 s	20	20	40	he s f
150	20	10	30	i f m	40	35	75	i f m	..	..	..	..	..	..	..	..	..	..	..	..
160	25	15	40	i f m	25	35	60	i f m	20	10	30	i i m	70	70	140	2 s	30	30	60	he s f
170	..	..	..	..	20	30	50	i f m	..	..	..	..	..	..	..	..	..	..	..	..
180	60	45	105	i f m	15	35	50	i f m	20	30	50	i f m	70	70	140	2 s	40	40	80	he s f
190	..	..	..	..	15	25	40	i f m	..	..	..	..	..	..	..	..	..	..	..	..
200	60	20	80	i f m	25	15	40	i f m	20	30	50	i f m	70	70	140	2 s	50	50	100	he s f
210	..	..	..	..	20	15	35	2 s	..	..	..	..	..	..	..	..	..	..	..	..
220	20	30	50	i f m	15	20	35	2 s	20	30	50	i f m	70	70	140	2 s	60	60	120	he s f
230	..	..	..	..	20	25	45	i f m	..	..	..	..	..	..	..	..	..	..	..	..
240	60	40	100	i s f	20	30	50	i s f	40	30	70	2 s	70	70	140	2 s	20	20	40	he s f
250	..	..	..	..	20	25	45	i s f	..	..	..	..	..	..	..	..	..	..	..	..
260	60	45	105	2 s	15	20	35	i s f	30	10	40	i f m	65	65	130	2 s	15	15	30	he s f
270	..	..	..	..	25	30	55	2 s	..	..	..	..	..	..	..	..	..	..	..	..
280	60	30	90	2 s	25	25	50	i i s f	20	20	40	i f m	70	70	140	2 s	30	30	60	he s f
290	..	..	..	..	25	35	60	2 s	..	..	..	..	..	..	..	..	..	..	..	..
300	60	45	105	2 s	35	45	80	2 s	20	20	40	i f m	70	70	140	2 s	35	35	70	he s f
310	..	..	..	..	35	40	75	i f m	..	..	..	..	..	..	..	..	..	..	..	..
320	60	45	105	2 s	60	15	75	i f m	10	20	30	i f m	75	75	150	2 s	45	45	90	he s f

Legend: * s moved from L to R. See text, p. 90, for explanation of other symbols.

TABLE VI. *Continued*

O: Interval in σ	S Localization in ° L	R	Total	Description	P Localization in ° L	R	Total	Description	M Localization in ° L	R	Total	Description	L Localization in ° L	R	Total	Description
0	0	0	0	—	0	0	0	—	0	0	0	—	0	0	0	..
5	5	10	15	2 s	..	..	..	..	15	15	30	2 s	..	..	..	..
10	−5	5	0	—	..	30	0	..	15	15	30	2 s	..	..	..	..
15	2	2	4	he s f	..	..	..	..	30	30	60	i s f	..	..	..	..
20	2	2	4	he s f	0	15	15	he s f	30	30	60	i s f	..	..	..	..
25	5	5	10	he s f	..	..	..	..	30	30	60	i s f	0	0	0	2 s
30	10	10	20	he s f	0	23	23	he f m	30	30	60	2 s	10	10	20	2 s
35	5	5	10	he s f	..	..	..	..	30	30	60	2 s	10	10	20	2 s
40	5	5	10	he s f	5	22	27	he f m	30	30	60	2 s	0	0	0	2 s
45	5	5	10	he s f	..	..	..	..	30	30	60	2 s	20	20	40	i f m
50	5	5	10	he s f	10	30	40	2 s	30	30	60	2 s	20	20	40	i f m
55	10	10	20	he s f	..	..	..	..	30	30	60	i f m				
60	10	10	20	2 s	10	15	25	2 s	30	30	60	i f m				
65	10	10	20	2 s	..	..	..	..	30	30	60	i f m				
70	15	15	30	2 s	10	15	25	2 s	30	30	60	i f m				
75	10	10	20	ho i m	..	..	..	..	30	30	60	2 s				
80	10	10	20	ho i m	10	15	25	2 s								
85	10	10	20	ho i m	..	..	..	..								
90	15	15	30	2 s	10	25	35	2 s								
95	20	20	40	ho i m	..	..	..	..								
100	20	20	40	ho i m	10	30	40	2 s								
110	25	25	50	2 s												

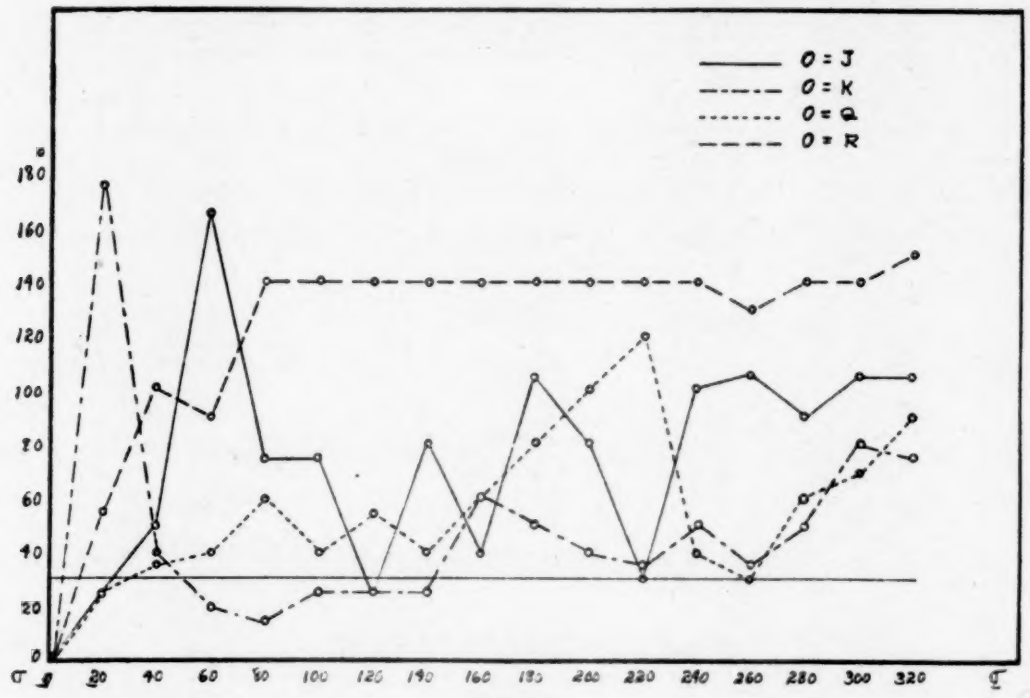

FIG. 7a

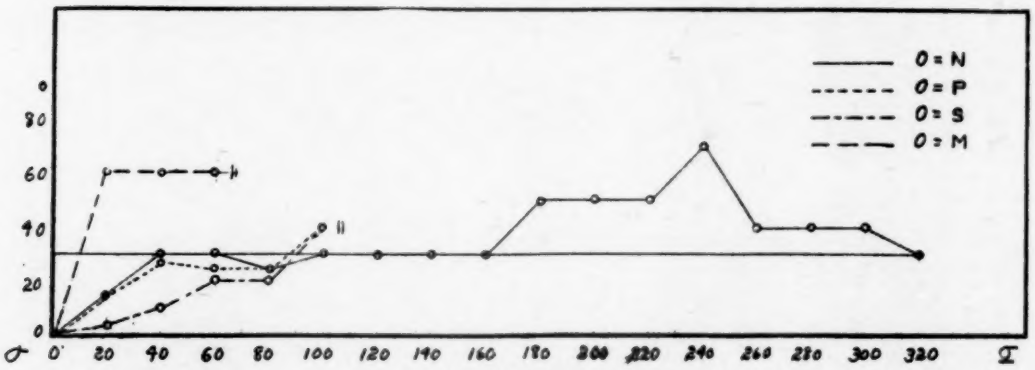

FIG. 7b

FIG. 7. Graphs of total phenomenal distance between terminal sounds for eight *O*s in Series VI
horizontal line at 30° = angular distance between receivers

Question (to K): "How does 'sound carried over' differ from 'sound not carried over'?"

Answer: "When it carries over a feeling goes with it—a feeling that there are two isolated spots connected by a line which moves from one to the other. That line comes in kinæsthetic and visual imagery; sometimes it comes in auditory imagery. That is, when sound 'carries over' it is in terms of imagery. I think I noticed the first time I observed that sometimes the second sound began both in space and time where the first left off. That was in places where the sounds overlapped. When the time is longer then the 'carrying over' is only in imagery."

N. "The terminal sounds are short staccato-like sounds. The intervening space suggests sizzling; it gives me the idea of lightning passing through the air with a slight accompaniment of sound." "This sound between is not as

real as the other sounds; sometimes it seems almost as if it came out of the imagination."

Question: "Where does the sound extend?"

"It usually seems that I can hear it start but that I can not always hear it finish. Maybe that is because the time is so short. It seems like a skyrocket starting out, but I can't always hear the finish."

A few trials were then given this *O* at the end of the regular series with instructions to try to hear two disconnected sounds.

"I can't hear them as separate. Some kind of connection exists between them; the sound seems to be continuous."

R. "I never heard anything between the terminal sounds. The first ones were quite a bit faster than the last ones tonight and they were not localized the same."

Q. "They remind me of an hour-glass. I think that is because the sound was less intense in the middle. I had these visual images but I really heard the sound move."

A few trials were then given this *O* at the end of the regular series with instructions to hear two disconnected sounds.

"They were not two separate sounds, the one blended into the other." "There was a faint hum between them." "I can't help it, I can't hear them as two separate sounds."

S. "I think I noticed movement more this time" (than in Series IV) "because I was watching more closely for it."

P. "The filling-in or travelling is something different from the terminals. It is partly visual imagery. It isn't as real as the terminal sounds. It was something that travelled from the first click to the second but it was not the click that travelled."

M. "There was not movement but image of movement, and that happened only in a few cases. When they are nearer together there is not even the idea of movement."

L. "In the last two trials the sound seemed continuous. It wasn't a sense of movement as, for example, of a train passing, but it seemed to be there."

The figures show such large individual differences in localization and such large variations in the localizations of a single individual that it would hardly be safe to generalize beyond saying that there is little or no consistency in the reports. Something in the physical conditions must be largely responsible for this, since these same *O*s gave reports in Series IV which were very much alike.

The receivers in this series (Series VI) were placed approximately 15° away from the median plane. This is near one of the transition points which *Starch* (**20**, p. 17 ff.) mentions, where "localization is more difficult than in others, apparently because there is no means of discrimination." Is this, perhaps, one of the essential conditions for the perception of movement? The fact that the trained *O*s were somewhat more consistent in

their judgments can be explained on the basis of more practice in observing under these conditions (20, p. 25). But then D's reports of movement appear to stand against the argument which involves this as an essential condition, as do also our results in Series I unless it be accepted that there our conditions were too difficult.

In any event, the amount and direction of "error" of localization appear to have little to do with perception of movement. J, who reported imaginal movement through 250 σ, greatly overreached the actual physical conditions in his localizations. But K, who, except at 20 σ, localized the sounds nearer the actual position of the receivers, and N, who localized them inside or on the line of the receivers, both heard movement through 320 σ. At the same time it is interesting to see that R, the only one of the untrained group who did not report movement, overreached the "objective" separation of the receivers by more than 350 per cent throughout the greater part of the series.

So far as the results of this series and Series IV are concerned it seems a plausible hypothesis that uncertain localization plus a "set" or "preparedness" for movement are at least very important conditions for apparent movement. But against this hypothesis stand the reports of D and some later data.

Series VII a and b

Procedure. Before we should attempt to draw conclusions regarding the effect of position of receivers, we thought it advisable to check the influence of the stimuli themselves by reversing the receivers so that receiver B was on the *O*'s right and clicked first. For this test all other conditions remained the same as in the last two series. *O*s D and I (trained) and J (untrained) were tested. The trained *O*s had the usual instructions, to describe what they heard; the untrained *O* was given the same instruction he had just had in Series VI.

D observed in another brief series, VIIb, in which all conditions were the same except that a pair of Western Electric receivers No. 509W were substituted for the usual ones. These new receivers were very different from the others in tonal quality.

The results. For the purpose of easy comparison Fig. 8 presents localization curves for the three *O*s both for this series and for Series V and VI in which receiver A was on the right and sounded first. Except in the case of I the differences are negligible. Perhaps the difference between I's two graphs can be accounted for by the fact that he worked with a cold in the head on the day that the localizations were made for graph b. There was no opportunity to test him again.

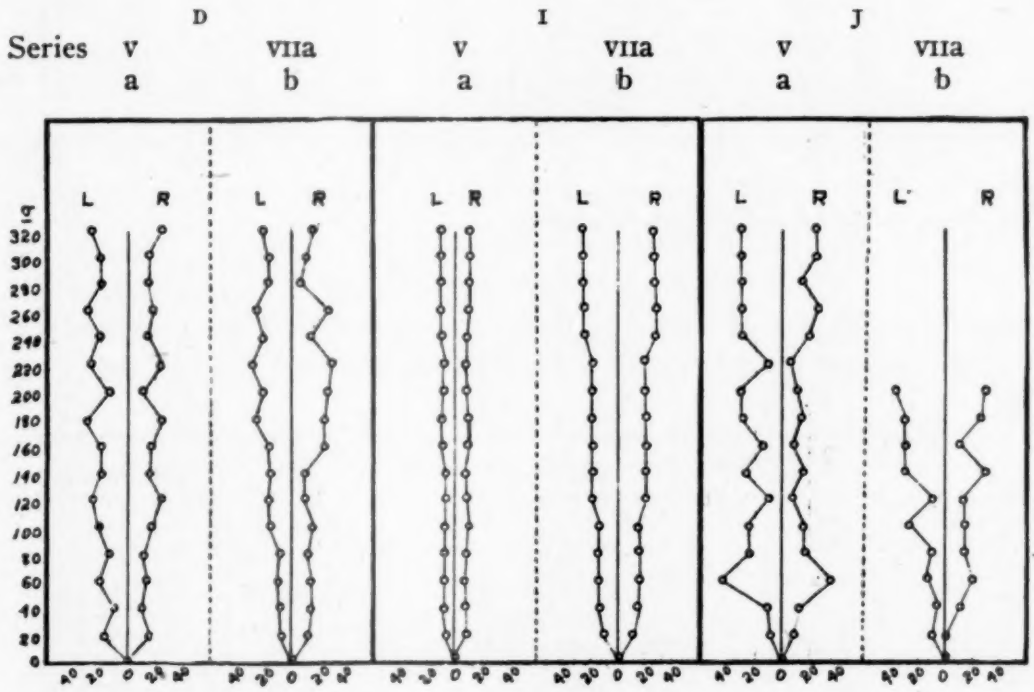

FIG. 8. Localization graphs for three *O*s in Series V and Series VIIa
a. Receiver A on right and sounding first
b. Receiver B on right and sounding first

Table VIIa presents symbolically the reports of movement. The table arbitrarily ends two steps beyond the last report of movement by any of the *O*s. From that point on they all heard discrete sounds.

Table VIIb reports the results for D with different receivers. Comparing these results with those in Table VIIa, we see that the phenomenal distance is somewhat shorter with the new receivers, but that the reports of movement are not essentially different.

TABLE VIIa. *Results of Series VIIa presenting L and R localizations, total phenomenal distance between sounds, and schematic descriptions*

O:	D				I				J			
	Localization in °				Localization in °				Localization in °			
Interval in σ	L	R	Total	Description	L	R	Total	Description	L	R	Total	Description
0	0	0	0	—	0	0	0	—	0	0	0	—
10	−5	11	6	ho s f	10	10	20	2 s	10	5	15	i f m
20	5	11	16	2 s	10	10	20	2 s	7	0	7	i f m
30	1	10	11	ho s f	15	15	30	i s f	15	18	33	i f m
40	8	13	21	ho i m	15	15	30	2 s	5	10	15	i f m
50	8	11	19	ho f m	15	15	30	2 s	25	30	55	i f m
60	10	13	23	ho i m	15	15	30	2 s	15	20	35	i f m
70	13	15	28	ho i m	15	15	30	2 s	15	15	30	i f m
80	8	12	20	ho s f	15	15	30	2 s	10	15	25	i f m
90	10	12	22	ho i m	15	15	30	2 s	20	25	45	i f m
100	14	17	31	2 s	15	15	30	2 s	22	15	37	i f m
110	14	18	32	ho s f	15	15	30	2 s	15	15	30	i f m
120	15	10	25	ho e m	20	20	40	2 s	10	15	25	i f m
130	15	10	25	2 s	20	20	40	2 s	20	23	43	i f m
140	13	10	23	2 s	20	20	40	2 s	30	30	60	i f m
160	18	22	40	2 s	20	20	40	2 s	30	10	40	2 s
180	25	22	47	2 s	20	20	40	2 s	30	25	55	2 s

See text, p. 90, for explanation of symbols.

TABLE VIIb. *Results of Series VIIb presenting L and R localizations, total phenomenal distance between sounds, and schematic descriptions*

O:	D				D			
	Localization in °				Localization in °			
Interval in σ	L	R	Total	Description	L	R	Total	Description
0	0	0	0	—	0	0	0	—
10	0	3	3	2 s	0	0	0	—
20	4	3	7	2 s	0	0	0	—
30	2	4	6	2 s	0	2	2	ho f m
40	2	4	6	ho i m	1	4	5	ho f m
50	3	6	9	ho i m	1	4	5	ho f m
60	3	5	8	ho i m	1	4	5	ho f m
70	4	6	10	ho i m	1	6	7	ho i m
80	3	6	9	ho e m	3	4	7	ho i m
90	4	7	11	2 s	1	5	6	ho e m
100	6	6	12	2 s	6	5	11	2 s
110	4	8	12	2 s	6	7	13	2 s
120	4	7	11	2 s	6	7	13	2 s
130	10	5	15	2 s	4	3	7	2 s
140	6	9	15	2 s	8	10	18	2 s
160	6	10	16	2 s				
180	10	14	24	2 s				
200	9	12	21	2 s				
220	4	10	14	2 s				
240	4	11	15	2 s				
260	6	15	21	2 s				
280	5	11	16	2 s				
300	3	10	13	ho e m				
320	6	10	16	2 s				

See text, p. 90, for explanation of symbols.

The results in each case are sufficiently like those for the same *O* in Series V or VI to warrant the conclusion that the general results we have obtained are not attributable to small differences in the stimuli but to some other factor or factors.

Series VIII

Procedure. If the factor of suggestion was the most important one for perception of movement for the untrained *O*s in Series VI and for D in Series V then it would seem reasonable to expect the *O*s now to perceive it under the conditions of Series III and IV where the receivers were placed 2 m. apart.

Three *O*s, J, N and D, were selected. They had not heard movement when the receivers were placed 2 m. apart but had reported it when they were 50 cm. apart. D was given a complete series from 0 σ to 320 σ inclusive. J and N were given as many trials in ascending order as their time permitted. J's series ran through 240 σ; N's stopped at 70 σ. J and N were given their usual instructions to describe the movement, and D was, as usual, just asked to describe what he heard. Table VIII shows the intervals which were presented to each *O*.

The results. The results are scanty and not much can be con-

TABLE VIII. *Results of Series VIII showing left and right localizations, total phenomenal distance between sounds, and schematic descriptions*

O:	D				J				N			
Interval in σ	Localization in ° L	R	Total	Description	Localization in ° L	R	Total	Description	Localization in ° L	R	Total	Description
0	0	0	0	—	0	0	0	—	0	0	0	—
5	—	85	0	—	75	75	150	*i f m	..	..	..	..
10	—	80	0	—	..	..	..	..	..	..	..	he s f
15	—	80	0	—	60	90	150	*ho f m	..	..	..	..
20	—	80	0	—	..	..	..	..	..	..	..	he f m
25	—	75	0	—	75	90	165	i f m	..	..	..	..
30	90	80	170	2 s	..	..	..	..	..	..	..	he f m
35	80	80	160	2 s	..	..	..	..	..	..	..	..
40	90	85	175	2 s	..	..	..	..	..	..	..	he f m
45	90	80	170	2 s	..	..	..	..	..	..	..	..
50	87	80	167	2 s	75	90	165	i f m	..	..	..	he f m
55	90	75	165	2 s	..	..	..	..	..	..	..	..
60	88	87	175	2 s	..	..	..	..	..	..	..	he i & e m
65	88	86	174	2 s	..	..	..	..	..	..	..	..
70	90	88	178	2 s	..	..	..	..	..	..	..	he f m
75	..	..	..	..	75	90	165	i f m				
80	90	85	175	2 s	..	..	..	..				
90	86	85	171	2 s	..	..	..	..				
100	90	80	170	2 s	75	90	165	i f m				
120	85	78	163	2 s	90	90	180	i f m				
140	85	80	165	2 s	75	75	150	i f m				
160	86	85	171	2 s	90	90	180	i f m				
180	85	80	165	2 s	90	90	180	i f m				
200	90	86	176	2 s	90	90	180	2 s				
220	90	85	175	2 s	90	90	180	2 s				
240	85	80	165	2 s	90	75	165	2 s				
260	87	87	174	2 s								
280	87	75	162	2 s								
300	90	80	170	2 s								
320	85	75	160	2 s								

* s moved from L to R. See text, p. 90, for explanation of other symbols.

cluded from them. It may be somewhat significant, however, that J and N, who had not reported movement under this condition earlier, now did so. N heard heterogeneous movement in all of the trials which were presented to her (through 70 σ) except at 10 σ where she heard only heterogeneous filling. J reported movement, usually imaginal movement, in all of his trials through 180 σ, 15 σ excepted, and from that point on heard only successive sounds. Why then did not D perceive it? There is nothing in our data to answer this question finally, but we suggest that the cue to the answer lies in the fact that when D hears movement it is the click itself which moves (homogeneous movement), whereas for the other two *O*s it is always imaginal or heterogeneous movement (except in one trial for each of them). So far as this study is concerned, however, this question is left open for further investigation. It is the homogeneous movement which D reports that we believe to be comparable with the apparent movement usually reported in vision, but we can draw no conclusions from one *O*.

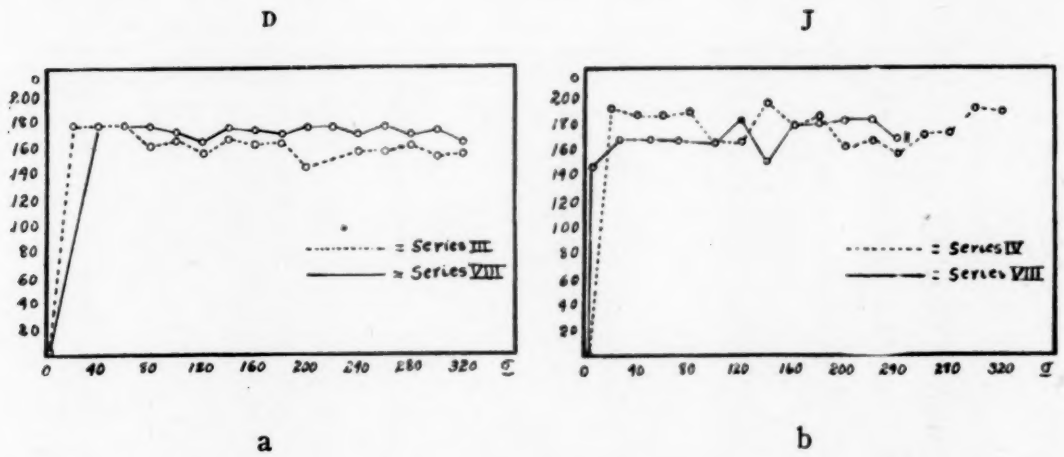

FIG. 9. Graphs showing total phenomenal distance between sounds for *O*s D and J in Series III, IV and VIII (before and after hearing movement)

Fig. 9 shows that there was no appreciable difference in extent of phenomenal distance either between *O*s or between the two graphs for individual *O*s. The total "objective" distance was 90°. There is no graph for N since she did not localize sounds in these trials.

Series IX

Procedure. In our last check on the influence of suggestion we gave to our regular *O*s the instructions to observe movement which we had earlier given to the untrained *O*s. The physical conditions were the same as in Series V (receivers one-half meter apart) because those had been found to be, in general, the most favorable of our conditions for movement. *O*s B, C and I served in this series; D was omitted because he had already spontaneously reported movement. The series ascended by steps of 10 σ through 140 σ, and from that point on by 20 σ through 320 σ. For I part of the series was repeated. There was a total of 83 trials.

TABLE IX. *Results of Series IX presenting L and R localizations, total phenomenal distance between sounds, and schematic descriptions*

O:	B				C				I			
Interval in σ	Localization in ° L	R	Total	Description	Localization in ° L	R	Total	Description	Localization in ° L	R	Total	Description
0	0	0	0	—	0	0	0	—	0	0	0	—
10	1	1	2	2 s	10	10	20	he s f	0	0	0	2 s
20	1	1	2	2 s	10	10	20	2 s	0	0	0	2 s
30	6	6	12	2 s	10	10	20	2 s	2	2	4	*i f m
40	13	13	26	2 s	15	10	25	2 s	2	2	4	2 s
50	13	13	26	2 s	10	10	20	2 s	15	15	30	i f m
60	15	10	25	2 s	10	10	20	2 s	10	0	10	i s f
70	23	15	38	2 s	15	5	20	he f m	10	0	10	2 s
80	13	10	23	2 s	15	5	20	he f m	10	10	20	i s f
90	23	10	33	2 s	5	5	10	he f m	5	5	10	2 s
100	10	20	30	2 s	10	10	20	he f m	15	0	15	i f m
110	13	15	28	2 s	10	10	20	2 s	15	0	15	i f m
120	10	23	33	2 s	15	15	30	2 s	15	3	18	i f m
130	10	30	40	2 s	15	15	30	2 s	15	0	15	i f m
140	10	30	40	2 s	15	10	25	2 s	15	5	20	i f m
160	10	33	43	2 s	15	15	30	2 s	10	0	10	2 s
180	13	33	46	2 s	10	10	20	2 s	20	0	20	2 s
200	10	38	48	2 s	10	10	20	2 s	30	0	30	2 s
220	10	40	50	2 s	15	15	30	2 s	30	0	30	2 s
240	10	43	53	2 s	10	10	20	2 s	30	0	30	2 s
260	10	38	48	2 s	10	10	20	2 s	20	0	20	2 s
280	10	45	55	2 s	30	30	60	2 s	30	0	30	2 s
300	10	43	53	2 s	15	15	30	2 s	30	0	30	2 s
320	15	43	58	2 s	10	10	20	2 s	30	0	30	2 s

* s moved from L to R. See text, p. 90, for explanation of other symbols.

The results. Table IX gives the results. B reported all of the sounds as discrete with no movement or filling between. C reported heterogeneous filling at 10 σ and heterogeneous movement at 70 σ. I reported imaginal movement in 16 per cent of the trials and imaginal filling in five per cent of them. Since C had reported no movement in hundreds of observations before,

and I had reported it only once, it seems likely that if more time were given for breaking down the "set" which they had acquired for discrete sounds these *O*s would report movement more frequently. This assumption was not tested further with these *O*s. Results in Series IV and VI have shown us that the influence of this suggestion is not invariable.

C. Miscellaneous experiments

The three series next to be reported are rather widely different in nature. Series XI came early in the development of the whole study; Series X came near the end but before the regular *O*s had been given instructions to observe movement; and Series XII was the last in the study and used *O*s who had not worked in the experiments before. Each series was but very briefly exploratory.

Series X

It was suggested that perhaps something in a situation in which clicks were produced by moving receivers would encourage the perception of movement. Even though the click is of very short duration it might conceivably be long enough to make the movement perceptible.

Procedure. The receivers were mounted on a "pendulum" which consisted of a wooden cross-bar support for the receivers suspended from the ceiling by cords, one vertical and two diagonal, in order to direct the course of the receivers in a straight line. The receivers were placed 50 cm. apart as in Series V, VI and VII. The release of the pendulum was not automatic but was made, upon signal, by E_2 who was stationed behind the curtain in the soundproof room. The release was noiseless. Preliminary practice by the two *E*s made it possible to produce the two clicks when the center of the pendulum arm lay within a range of 15° on either side of *O*'s median line. The procedure was crude, but results of the preliminary trials did not encourage further refinement of apparatus. From 20 to 27 exposures were presented to each *O* with a constant temporal interval of 75 σ. This interval had been found to be one of

the most favorable for movement. Other conditions were the same as in Series III. The instructions were the same ones that these *O*s had had throughout all of their observations—to describe fully what they heard. Trained *O*s B, C, D and I served in this series.

The results. Neither C, B nor I reported anything but two discrete sounds. In 39 per cent of his reports D heard initial homogeneous movement, and once heard homogeneous end movement. These are in close agreement with his reports for the same or adjoining intervals in Series V, VIIa, and VIIb. His reports of localization show that both sounds sometimes occurred on the right of the median plane (slow release of pendulum), and his tone of voice showed that that somewhat disturbed him. This may account for the fact that he reported movement in only 39 per cent of the trials, but there is nothing in the results from the actual physical motion of the receivers as we produced it to lead us to conclude that such motion favors the perception of movement.

Series XI

Procedure. In series XI the *O*s were seated in a horizontal line between the receivers. The series was suggested by experiments on sound localization in which similar conditions had prevailed and in which moving sound had been spontaneously reported at small temporal intervals (*e.g., Trimble* (22), *Wittmann* (24), *etc.*). The receivers were attached to the Seashore sound perimeter. Receiver A was in line with *O*'s right ear and 25 cm. from it; receiver B was similarily placed with reference to the left ear. Other physical conditions were the same as in Series II where the fainter clicks were used and the intensities were perceptually equal.

Three relatively untrained *O*s, E, F and G, were used, and the position of the receivers was necessarily known to them. The room was lighted during the experiment. The instructions read: "At the light signal sit straight in your chair and hold your head in position to fixate this point" (a point directly in front of *O*). "A few seconds after the signal you will hear

sound moving from the position of one receiver to the other. Note and describe this movement."

Ascending series were conducted by steps of 1 σ each from 0 σ to 150 σ.

The results. The results were almost entirely negative. E began to hear the sounds as two at 4 σ, but her only positive report of movement came at the interval of 128 σ when she said, "I am beginning to wonder about movement but I don't think there is any yet. It seemed as if I heard it go from the right into the head; then I didn't hear it from the other side."

G heard the sounds as two from 3 σ on. At 33 σ he said, "It seems as though there is a connection between the two and that the right communicates to the left. The right click precedes; at one-half the length of time of the first the second click occurs."

F heard the sounds as two from 2 σ on. Her only comment about movement was made at the middle of the series. "When the first click is real sharp and quick it resembles cases when people make a clicking sound with the tongue and throw it at you. Something *suggests* movement. It comes only with the first of the pair of clicks."

These reports indicate that there certainly was nothing in the stimulus nor in the suggestion of the instructions to compel the perception of movement for these *O*s.

Series XII

The conditions in the series last reported more nearly approached the conditions for dichotic hearing than those of any others of our preceding series. Although he was not in search of apparent movement, *Wittmann* found that with this condition, and also with the receivers against the ears, the sound "wandered about in different routes within the head" (**24**, p. 64), and *Klemm* (**14**) reports similar results.

Procedure. As a last effort before this study was obliged to end, we conducted a short series with the receivers against the ears and without any suggestion regarding movement to the *O*s. Three relatively untrained Os, X, Y and Z, were used. The series progressed by steps of 10 σ, with receiver A on the right

and clicking first, from 0 σ through 140 σ, and from that point on by 20 σ through 320 σ. With X the series was repeated from 0 σ through 60 σ. With Z it was similarly repeated through 60 σ, and another complete series was conducted with the receivers reversed so receiver B was on the right and clicked first.

The series were hurried and the procedure relatively uncontrolled. It can be considered only as the barest preliminary to further study, which is now being made.

We were fully aware that constant conditions could not be maintained in this way. A further difficulty with the procedure lay in the fact that when the receivers were brought in such close contact with the ears a click from them became barely perceptible when switches C_1 and C_2 broke the short circuit across S_1 and S_2, so that three instead of just two sounds were often heard.

The *O*s were instructed: "At the light signal place the receivers with equal light pressure against the ears. A few seconds after the signal and auditory stimulus will be presented. Describe what you hear as fully as you can."

The results. All of the *O*s spontaneously reported movement, X in 65 per cent of the trials, Y in 25 per cent of his trials, and Z in 60 per cent of his trials. In his second series Z reported movement in 90 per cent of the trials—movement at every interval above the one of 20 σ, showing that practice favored the perception of movement. Z remarked, "I think I noticed more movement today because I was looking for it."

The moving sound sometimes progressed in a straight line through the head from right to left; sometimes it moved in a bowed or angular line, sometimes it moved only part of the way through the head. The following reports are typical:

Observer X

70 σ. "A click in the right ear; then it seemed to die down, and then about halfway in the head it picked up and travelled to the other ear where it ended in a click."

100 σ. "An echo, then a click in the right, then a faint thread of sound travelled to the left where I got a fainter click."

130 σ. "I got the echo-like sound, then a click in the right ear; then one in the left. There was time between. There seemed to be a thread of connection, but it seemed just *to be there* and not moving.

160 σ. "A loud click in the right ear; then it echoed off into a thread moving toward the other ear; but before it reached the other ear the echo got louder again. Then came the second click not so loud as the first."

240 σ. "I couldn't tell where the first click came. The second came in the right ear and moved to the left. It went through the head all the way across. The first click may have been in my head."

300 σ. "A click in the right ear; then it travelled in a bow up through the head to the left ear, where I got another click."

320 σ. "I got a click in the right ear. Then it travelled to the left, rounding toward the front of the head and ended in a click in the left ear."

Observer Y

70 σ. "The sound began halfway between the ears, then spread as two sounds to each ear. It travelled in the head, but it didn't quite reach the ears."

90 σ. "The sound originated in the head. Then it separated into two parts that travelled up and away toward the ears. It didn't quite reach the ears but it got closer to the right one than to the left."

100 σ. "The first click was in the right side of the head; the second one came in two places, but it was not connected with the first sound. There was no movement this time."

240 σ. "The sound moved. The point of origin was just inside the right ear. The second part of the sound moved on a line between the two ears. I couldn't tell for sure which way it moved but probably toward the left ear."

Observer Z, First Series

20 σ. "Two sounds in the right ear; a broken sound."

30 σ. "It seemed to shoot across from the right to the left, making an angle toward the front of the head just left of median. It gave a 'sensation' of light as it went."

50 σ. "I got that 'through' experience again. I judged it to go from left to right."

180 σ. "The first click was in the right ear. Then it travelled to the middle of the head, where there was a click together with a faint simultaneous click in the left."

220 σ. "There was a real loud click in the right ear; it moved into the head two or three inches, where there was a less loud click."

300 σ. "It moved from right to left."

320 σ. "The first sound seemed to move into the head two inches while I heard it; then it reappeared on the other side. Though I couldn't see the path all the way across I would swear it was the same sound that came out at the other side."

Observer Z, Third Series with Receivers Reversed

10 σ. "No movement; almost simultaneous clicks in both ears like two dots together so they touched."

30 σ. "A suggestion of movement from right to left, not very real movement. The sounds followed one another real closely."

40 σ. "A faint one first in the middle of the head. It split and went both ways to the ears, and then seemed to go back to the middle."

130 σ. "There was movement but I couldn't tell where it went."

220 σ. "There was movement from right to left. The center sound was so faint it didn't seem to enter in."

320 σ. "In the right ear first; then it went three-eighths of an inch into

the head; then there was empty space and again movement for three-eighths of an inch toward the left ear."

"It is *the clicks* which move. The sound has very definite localizations. I feel as if I could put my finger on the sound if I could only get into the head."

We seem to have found a condition which is more favorable to movement. The reports of the *O*s given above show that the experience of movement was very real; Z felt as if he could "put his finger on it."

The presence of the third click in this series makes it not directly comparable with our other series. The fact that movement was sometimes reported when only two clicks were heard does not necessarily mean that the third click was not there and operative. It may have fused with the first click of the stimulus pair.

VII. Summary and discussion. Although compulsory conditions for apparent movement were not found in this experiment, we feel that we may have gained some cues toward a solution to our problem. In Series I we tried three trained *O*s with the receivers in a vertical position in the median plane. Two *O*s were unable to hear the sounds in different places; hence their results would necessarily be negative, unless we should find *beta* or *gamma* movement in audition as well as in vision. To the *E* of this experiment, who herself observed under many conditions during the conduct of the experiment, that seems an entirely possible observation. It is one, however, which requires a very analytical attitude. D described a visually filled space in this first series. It is possible that this was the same sort of thing which in later series he designated as movement. D was, by far, the most analytical of all of the *O*s. His descriptions were always fuller and more detailed than those of any other *O*s, and, as we have seen, he was the one who described homogeneous movement under more of the conditions than any other *O*. We are inclined to believe that it was his analytic attitude that led him to notice the movement he reported. This means that we are suggesting for auditory movement an attitude contrary to the one that has been reported as most favorable for visual movement.

In Series II (faint clicks; receivers 1 m. apart; d = 1 m.) we got localization pictures which show very decidedly the *abstandes Verkurzung* which *Kester* (12, p. 84) reported in his experiments in sound localization, and which *Scholz* (17) found with sources of sound 1 m. apart in the range of temporal intervals in which movement occurred. Yet our results from four trained *O*s contained no reports of movement. Our graphs show that this region of shortening was usually both preceded and followed by marked, and sometimes sudden, increases in phenomenal distance. This increase in phenomenal distance usually exceeded the actual objective distance, and sometimes exceeded the distance between the two sounds computed from the *O*'s localization of each click when it occurred alone.

In Series III (trained *O*s; receivers 2 m. apart; d = 1 m.) there were no reports of movement or stationary filling. At all intervals above that of 15 σ the phenomenal distance exceeded the "objective" distance for B, C and D. For I it was greatly shortened. For C and I it was in general greater than the distance between localizations of the clicks when they were sounded alone; for B and D it was less.

In Series IV (untrained *O*s; receivers 2 m. apart; d = 1 m.; instructions to observe movement) one *O* reported heterogeneous full, initial and end movement throughout the entire series; one *O* reported heterogeneous filling at 5 and 10 σ; and another *O* a few times reported imaginal movement.

In Series V (trained *O*s; receivers 50 cm. apart; d = 1 m.) D reported homogeneous movement and filling, and heterogeneous filling in 53 per cent of the trials for intervals below 120 σ. I reported imaginal filling between 30 σ and 50 σ inclusive. Localization seemed to be somewhat less stable here, and the shortening of phenomenal distance bore an irregular relation to the distance between localizations of the clicks when sounded alone. This shortening and extension can best be shown and discussed by means of Fig. 10. It shows for *O*s A, B, C, D and I in Series II, III and V the relation in percentages of the total phenomenal distance at every 20 σ increase in interval to the

distance between the two sounds computed from *O*'s localizations of each click when it occurred alone. For A we have only one graph because he dropped out of the experiment after complet-

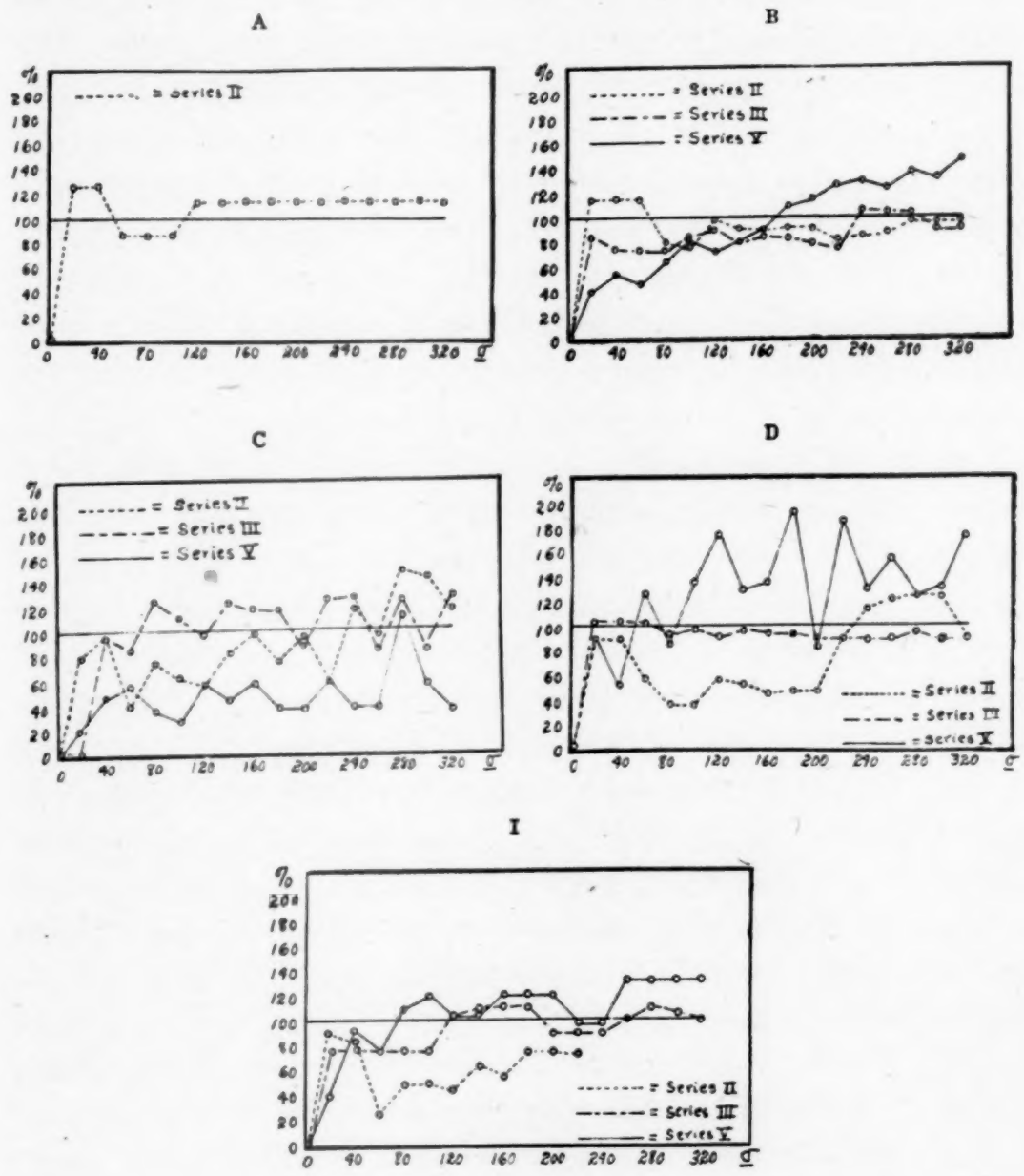

FIG. 10. Graphs showing effect of temporal interval upon phenomenal distance between sounds

ing Series II. The curve for Series II (1 m. of separation between receivers) shows approximately the same characteristic of a rather large percentage of shortening for C, I and D in the lower range. Near the interval of 200 σ C and D exceed the

100 per cent line. B and A exceed it throughout most of the entire range. The curve for Series III (2 m. of separation of receivers) falls nearer the 100 per cent line throughout the whole range than any of the others do; and the curves for Series V (50 cm. of separation of receivers) show the greatest individual variation of all. It will be remembered that in Series II there were no reports of movement but a few of stationary filling; that in Series III there were no reports of movement, and that only two of the untrained *O*s working with suggestion under the same conditions reported it; that in Series V, D reported movement fairly consistently between 0 σ and 120 σ, and most of the untrained *O*s reported some kind of movement in the parallel Series VI. We recall again the correspondence which *Scholz* found between extreme phenomenal shortening and movement. Whatever the relation between the two may be, it is apparently not a necessary one, for our two *O*s, B and C, whose reports were most conspicuously lacking in movement or stationary filling of sound, were the two whose curves for Series V show the greatest phenomenal shortening through at least the first half of our range. Further evidence lies in the fact that D, who in Series V reported movement through 80 σ, shows in that part of his curve little if any more shortening than he does in the curves for the other two series in which he reported no movement. On the other side of the argument lies the fact that the curve for I in Series IX (see Fig. 10), in which he reported imaginal movement between 0 σ and 130 σ, shows somewhat more shortening in the range of shorter intervals than his curve in Series V does. The curve for Series IX, however, is based on only one ascending series and must not, therefore, be given too great weight. To *E*, who observed in parts of all of the experiments with full knowledge of the conditions behind the curtain, there was very little of this shortening of phenomenal distance above the temporal interval of 5 σ. Yet, she observed movement and stationary filling for small intervals larger than 5 σ.

Series VI (untrained *O*s; receivers ½ m. apart; instructions to observe movement) brought some reports of movement from all except two of the untrained *O*s, and one of them reported filling though no movement. The largest range of intervals at which movement was reported lay between 40 σ and 320 σ. There were only occasional reports of homogeneous movement (only 6 per cent of all of the reports of movement), and 79 per cent of all the cases were imaginal movement.

Series VIII (trained *O*s; receivers 2 m. apart; *O*s had reported movement in Series V and VI) shows that suggestion had been a strong factor with the untrained *O*s who heard heterogeneous and imaginal movement. But for the *O* who was reporting homogeneous movement and was being more analytical, the fact that he had heard movement when the receivers were 50 cm. apart did not influence his reports when he again heard them with the 2 m. of separation. The factor of suggestion apparently is, as we should expect, an uncertain one.

The results from Series VIIb in which D observed with different receivers showed as many reports of movement as those for Series V in which all other conditions were the same. This seems to indicate that the phenomenon of movement is not largely dependent upon small differences in the stimuli.

The procedure involving dichotic hearing (Series XII) is the most promising of all those which we tested for compulsory conditions for movement, but is not yet adequately tested.

The different kinds of movement and filling reported are matter for speculation and further investigation. How, for example, shall we interpret the "buzzes" and "hums" and "feels" of the untrained *O*s who were put under extreme suggestion and who had very few scientific categories in which to describe what they heard? "Feeling" and "seeing" doubtless refer to imagery, in some cases produced perhaps entirely by the suggestive instructions. In many cases the *O*s themselves reported images. This alone, while it is apparent movement of a kind, is not the kind of movement we were looking for. In some

cases, *e.g.,* for D in Series V, VII and X, and for Z in Series XII, the movement or filling of sound was accompanied by visual imagery which was almost synæsthetic, but these *O*s were very sure that, in addition, they heard sound moving, and were able to describe intensive and qualitative differences in the sound which moved and to designate it as a sensory experience. Such analysis of one's own perception seems almost to be necessary in order to know what it is we are naming. Whether the entirely imaginal movement is the thing which *Wertheimer* designated as the pure *phi*-phenomenon we can not definitely say. It seems to have the necessary objective meaning without the objective accompaniment.

The heterogeneous movement and filling appear to be distinctly different from the purely imaginal kinds. At least the subject feels certain that the experience is sensory. The terms used, "a buzz," "a hum," "a sound accompanying lightning," *etc.,* suggest that accompanying imagery gives the sound its interpretation. How much the auditory part of the total situation is responsible for it is hard to say. The somewhat fuller description of the heterogeneous movement testifies to its more sensory character.

The descriptions of homogeneous movement and filling were the fullest. Whether it is characteristic of it that there is more to describe, or whether we got the reports which made us call it homogeneous because the *O*s who described it were analytic and noticed more descriptive items, is a debatable question. We accept the latter alternative. There was as much in the physical situation for one *O* as for another, but descriptions varied widely. There seems to be no possible answer but that a further determinant lies in the individual, whether it be in "set," attitude, or past experience, all of which have been considered important in apparent movement (11, p. 505). No attempt was made to measure the duration (psychological or physical) of our clicks. If they overlapped through the range of the reports of homogeneous movement then it would be reasonable to expect that the person who noticed more in the situation to describe regard-

ing qualitative and intensive changes would be the more likely to report movement.

In most of our series with the trained *O*s we tried to limit them to purely auditory cues. No doubt there was some influence of attentive expectancy as a given series progressed. *Young* (25) has pointed out that such expectancy as well as a visual sensory accompaniment of the auditory sensations may largely influence sound localizations. The probable influence of expectancy upon the phenomenon of auditory movement has been demonstrated in our series with untrained *O*s, with whom the influence was greater than with the trained *O*s. Our results in Series XI, in which we had no reports of movement, and in Series XII, in which there was a large per cent of reports of movement, show that full knowledge of the position of the sources of sound does not in itself produce or inhibit perception of movement. The results show rather that we have not yet found the right critical combination of conditions for movement. There has been nothing in most of our study of apparent auditory movement to lead us to attribute the homogeneous movement to a "gross meaning" as *Whitchurch* does (23, p. 489) with tactual movement, but rather to a refined meaning based on qualities noted under a somewhat analytic attitude. This statement, however, is not particularly pertinent to the brief series with dichotic hearing. Results there indicate that in that situation there is a more powerful physical or physiological determinant—one which is less dependent upon the individual attitude or set. The condition of bone conduction might conceivably be responsible. Perhaps we have simply here a more favorable condition for the ears to hear scattered sounds resulting from components in the complex sound source which do not "agree sufficiently well that the observer corrects them to a single position" (10, p. 41).

Although our total of 6,000 trials gave us but a small per cent of reports of movement (4 per cent) certain of the series were fruitful, and we believe that with suggestions gained from this study it will be possible to find compulsory conditions for apparent auditory movement. The following controls are suggested:

1. Sufficient control of stimuli to eliminate varying vertical localization which it seems must be a distracting factor in the situation.

2. Work with various modes of dichotic presentation.

3. Work with highly trained *O*s.

By way of conclusion we can say that under our conditions (1) we did not find compulsory conditions for apparent auditory movement; (2) we found, in so far as we got reports of movement, that the range of intervals within which movement occurred did not closely correspond to the range of phenomenal shortening of distance; (3) we found that differences in the quality of telephone receivers had, in a limited range of intervals, no appreciable effect upon the range and kind of movement; (4) we found in preliminary series certain conditions of dichotic hearing most favorable of all our conditions for movement.

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A "CENTRAL" EXPLANATION OF SOUND LOCALIZATION

by

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Since the early days of psychophysics, the history of experimental psychology shows that originally the main drive was toward a study of the conditions under which stimulation took place. Even though Weber for a time advocated a spatial sense,[1] and did much to analyze qualitatively the historic sense of "touch," his work was convincing in that it was firmly grounded on stimulus and end-organ to the extent that was possible in his time. From that day to this it has become very important that we should know exactly under what physical and physiological conditions an experimentally controlled series of mental processes is taking place so that we may repeat and vary those conditions at will. This first essential of all experimental research can be found in most of the investigations of the perception of sound localization. From one study to the next there has been a perfect succession of data enumerating and stipulating many of the physical factors under which sound localization is effective. While in general it is still true that quantitative work comes after qualitative description, in many instances the process was reversed. First, for example, Weber and others determined constants for the various j.n.d.'s; later studies undertook to describe qualitatively just how in a particular instance the two-point discrimination on the skin gradually took place. This minute qualitative analysis by Henri and Tawney revealed that there were various

[1] A free translation of *Ortsinn;* see Boring, E. G., A history of experimental psychology, N. Y., Century, 1929, pp. 92, 109 ff.; Wundt. W., Grundzüge d. physiol. Psychologie, 6th ed., Leipzig, Wilhelm Engelmann, 1910, Vol. II, p. 7; Klemm, O., A history of psychology (trans. Wilm and Pintner), N. Y., Scribners, 1914, pp. 328, 356.

stages of "twoness" with intermediate stages of dumb-bell-like connection.

Similar problems are now arising in connection with sound localization and allied phenomena. They have knocked on our door before but perhaps so faintly that we did not hear, or so intermittently that we did not attend to them. But now the quest is on, with the impetus behind it from several sources, among which the following may be enumerated. One challenge comes from *Gestalttheorie,* but also from other forms of theoretical psychology, to say nothing of the historical antecedent of phenomenology which attempted to lead us away from sensationalism and mental atomism into the higher forms of mental integration.[2] Most of us have recognized that the concepts of synthesis and perceptual patterning have been with us before, but there has certainly been a shift of emphasis and a new focus for thinking which have lead Boring, Trimble, Troland, Young, and others[3] to regard our problems in sound as explicable, not so much from the angle of the sensory organ of hearing or even from

[2] Almost every reviewer of a new doctrine, like that of *Gestalt,* has taken pains to show that it was not woven out of whole cloth, that the warp and woof of it came from perfectly obvious sources. John Mill's 'mental chemistry', Spencer's 'feelings of relation', James's 'feelings of *and, if, but,* and *by*', Calkins's 'relational elements', Erhenfels's 'Fundamente', Meinong's 'founded contents', Wundt's 'apperceptive synthesis', and Bentley's 'incorporation', are only a part of the fabric from which it was spun. It is gratuitous, on the other hand, to refer to structural psychology as a 'static point of view' as Bridges has recently done (Psychology, normal and abnormal, p. 4) or as 'sterile and narrow' as McDougall (Social psychology, p. 15) is in the habit of doing, when Titchener fairly and squarely faced the issue early in his development of the system (*v.* Experimental Psychology, 1901, Vol. I, Pt. I, p. 127 f; Pt. II, p. 228 f; Experimental psychology of the thought processes, 1909, p. 184 f, and Systematic psychology: prolegomena, 1929, p. 58 ff.).

[3] Boring, E. G. Auditory theory with special reference to intensity, volume and localization, *Amer. J. Psychol.,* 37, 1926, 157–188.

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the point of view of adequate stimulation as from the aspect of the higher cerebral centers and the consequent elaborations involved in these centers. From another angle the recent physiological thories of Cameron, Franz, and Lashley,[4] together with the work done in our laboratory by Travis[5] and others, have lead us to envisage our problems from the approach of higher neurological integrations as over against peripheral mechanisms. Finally the more direct evidence of actual experimental work quantitatively controlled and introspectively checked has suggested first faintly and then more insistently that even a problem like the perception of beats or of sound localization has other than sensory factors in it.

By way of introduction to the problem I have purposely emphasized the concept of *perception* in sound localization and I wish now to come more closely to terms with this important group of mental processes. Let me therefore make an analogy from the well-known field of illusions in visual perception to that of auditory perception. By way of reminder, we may review what every psychologist presumably knows. The geometrical optical illusions are largely conditioned by stimulus. Most of us are affected so uniformly that Seashore[6] and others have adopted the expression, "the law of illusion" to denote generalizations that can be drawn from our common experiences. Yet there are marked differences among individuals in the perception of even so simple an illusory pattern as the Müller-Lyer arrow-head figure and certainly there is a pronounced tendency toward cancellation of the effect when a class sees the instructor in the process of measuring out the lines as he draws the figure on the

[4] Cameron, N. Cerebral destruction in its relation to maze learning, *Psychol. Monog.*, 39, 1928, No. 1, 1–67.

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[5] Travis, L. E. The relation of voluntary movement to tremors, *J. Exper. Psychol.*, 12, 1929, 515–524.

[6] Seashore, C. E. Psychology in daily life, N. Y., Appleton, 1913, Chap. VI.

board. Flügel [7] has investigated the influence of fatigue on the illusion of reversible perspective, although he is led to assume that the effect may be quite specific. At any rate familiarity with the illusion and practice in an experiment have much to do with the perception even when the conditions of stimulation are entirely adequate. In other words, the sensory components though important, are not the only actors in the show. This can be readily demonstrated also in the perception of blot-pattern designs. Individuals have markedly different experiences when viewing these representations, some even failing to see "objects" when they are pointed out. Similar phenomena occur with some of the reversals of figure and ground suggested by Rubin and others as illustrative of *Gestalten.*[8]

Thus in the same way we may characterize such a complex phenomenon as sound localization. Young [9] has already indicated in his experiments on transposition of sounds across the sagittal plane that auditory localizations could be very definitely reversed and would then lead to adequate adjustment in terms of automatic motor responses under blindfold conditions. But when the eyes functioned normally and conflict arose, visual perception was dominant over auditory perception by way of motor adjustment of the body. It would have been interesting to learn what would have happened if the physical conditions for both eyes and ears had been reversed. The fact remains, however, that integration did occur on a higher than pure sensory level and that when complication appeared, as in the case of strabismus in the visual field itself, an adjustment was made in contradiction to the actual evidence from the ears. Similar reasons have led Trimble on the basis of work done in this laboratory to argue in favor of a difference-pattern as the distinguishing mark characterizing any two differently localized sounds.[10] This difference-

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[8] Ruckmick, C. A. The mental life, N. Y., Longmans Green, 1928, frontispiece and p. 12.

[9] *Op. cit.*, 429.

[10] Trimble, O. C. Some temporal aspects of sound localization, *Psychol. Monog.*, 38, 1928, No. 4, 172–225; A discrete impulse technique in sound localization, *Brit. J. Psychol.*, 19, 1928, 167–178.

pattern is physically analyzable. Some factors can be called prepotent as compared with others within certain limits. Difference in phase is preponent with low tones, difference in temporal arrival is operative with clicks of high pitch when the temporal disjunction is between .06 σ and .26 σ even though these differences are not perceptible directly. Intensive differences are prepotent over a wide range of pitches. But under the complex conditions of every-day life the patterns are complex and diverse with the possibility that one or more factors are leading in their influence but not introspectively analyzable. Troland carries the integration of various auditory factors to the higher cerebral levels where both conscious and unconscious phenomena are synthesized.[11] It is not a strange story in psychology, for we have the same situation in stereoscopic vision and other allied fields of perception.

The thesis of the present paper, then, is that in problems of sound localization, which are allied to problems in the perception of motion such as the phi-phenomenon as well as to all other problems in perception, there are at least three sets of conditions which must be rigorously taken into account. (1) The conditions of stimulus, namely all of the physical factors which are favorable or unfavorable for the production of any specific perception, should be minutely scrutinized and controlled. Many of the experiments done on sound localization from the psychophysical angle have stressed these factors. While we have made noteworthy progress in the allocation of such data to the various ranges of pitch and have otherwise independently controlled many of the component physical aspects, much work needs still to be done to settle disputed points and to formulate the results in accordance with an acceptable theory of hearing. The last study by Trimble[12] answers many of these questions. As our physical techniques advance, however, more adequate results can be anticipated. (2) The neurological substratum must also be investigated or at least suggestions from analogous studies in several of the contiguous fields should be taken into account. The

[11] *Op. cit.*, p. 353; The psychophysiology of auditory qualities and attributes, *J. Gen. Psychol.*, 2, 1929, 28–58.

[12] Trimble, O. C. *Op. cit., Amer. J. Psychol.*, 41, 1929, 564–576.

refractory phase, the requirements of the all-or-none theory of response, the indications of mutual inhibition[13] of afferent nerve currents, and the integration of the whole neural system at its various platforms are not to be overlooked. The mechanism of reception and response is, according to Lashley and others, not only very complex but at the present stage of knowledge very incomplete and unsatisfactory for a proper explanation of some of the conscious as well as of the unconscious components which are correlated with these mechanisms. (3) But for the psychologist some of the main difficulties lie in the direction of mental variants, involving past experience, both individual and racial, which are exhibited in such expressions as, cortical set (*Einstellung*), the unconsciously assumed, self assumed, or experimentally implanted *Aufgabe,* the attensive[14] attitudes which vary from time to time in a given observer, or a group of observers, and the effects of practice involving accumulated experience in

[13] Telford, C. W. The refractory phase of voluntary and associative responses, *J. Exper. Psychol.,* 14, 1931, 1–36. This study gives an indication of the effect of previous responses acting as a barrier against later voluntary responses, judgments and simple associative reactions, and shows that judgments of this sort depend upon the course of recovery, of excitability in still more elementary systems. The study of L. T. Spencer (The concept of the threshold and Heymans' law of inhibition, *J. Exper. Psychol.,* 11, 1928, 88–97) confirms the notion that the effect of inhibition can not be limited to one sensory modality but must be derived from all of the other modalities operative in the observer at the time.

[14] See Carr, H. A. Psychology of mental activity, N. Y., Longmans Green, 1925. In his discussion of the interpretation of spatial perception, illusion, and motion he states that "the accuracy of judgments is conditioned by the direction of attention", and that "the appreciation of the spatial aspects of objects again illustrates the dependence of perception upon the previous activities of the organism. It also demonstrates the truth of the doctrine . . . that any adaptive response to an object is influenced to some extent by the total sensory situation of the moment." In a noteworthy investigation Pintner and Anderson discovered that while judgments on illusory effects show no important correlation with general intelligence, they did find that with increasing age there is a gradual decrease of illusion which they are willing to explain in terms of attention. In addition, the factor of contrast and experience are declared to be operative in increasing the extent of the illusion with children. This is also corroborated by the work of Smith. See Pintner, R., and Anderson, N. M., The Müller-Lyer illusion with children and adults, *J. Exper. Psychol.,* 1, 1916, 200–210, and Smith W. G., A study of some correlations of the Müller-Lyer visual illusion and allied phenomena, *Brit. J. Psychol.,* 2, 1906, 16.

a given experimental series or carried over from previous experimental studies. I have purposely avoided references to the *Gestalt* literature to indicate that the main thesis which presents any analyzable content as a function of numerous other factors is equally germane to a so-called introspective psychology.

But my present purpose is to relate much that has gone before with the several theses that have recently come under my direction. For some time the "phantom sound" has been reported in investigations on sound localization. In the meantime contributions have come in on the problem of the phi-phenomenon in vision. The assignment of pitch to one or the other of the primary sources or to a third so-called "intertone" also provided conditions for the perception of a moving auditory quality. It was an easy transition to bring these facts into relation with the reported movement of pitch in the beating complex and with the perception of motion among sounds.

Hauge's work on the phi-phenomenon in beats published in a previous issue[15] and the Mathieson study reported in this number left us with many regrets. By way of positive contribution Hauge found no evidence for a moving pitch quality but, on the other hand, discovered that one stationary pitch value was gradually supplanted by another stationary pitch value. In the Mathieson study movement of sound analogous to movement among visual objects came like the proverbial "pulling of teeth." But in both of these attempts valuable theoretical and factual material is at hand in connection with the problem of sound localization.

The first important discovery related to the enormous influence of the cortical set for localization in sound as over against motion when only two discrete positions are given as in the phi-phenomenon in vision. Through several variations in space and time we were hardly able to produce motion even when directly suggested. One of the reasons undoubtedly lies in the cortical set for localization, that is against motion. Observers who had taken part in previous experiments on sound localization were

[15] Hauge, I. B. The application of phi-phenomena to beats, *Psychol. Monog.*, 38, 1928, No. 4, 39–49.

naturally prepared for reports in terms of this latent *Aufgabe*. But even those who were untrained in the laboratory were naturally set for the localization of sound at definite points. It may be noted that in the perception of motion where only sounding objects are involved, that is without visual cues, it is difficult apparently to get motion from two discrete points of presentation in every-day life. In our most common experiences, such as hearing trains roll by or aeroplanes buzzing overhead, the sound is continuously changing and calls up visual imagery that is often later checked by actual visual perception. Whenever possible, the kinæsthetic experience involved in turning the head or otherwise adjusting the body is very likely also a strong component. This is what led Münsterberg to a motor theory of sound localization. I have a strong suspicion from my study of rhythmic perception[16] that the motor phenomena are inherent in many of our perceptions if only in the form of a tendency to respond.

We found in the Mathieson study, as others have discovered in two-point tactual discrimination or in the perception of tactual forms,[17] that filling in between discrete stimuli is commonly done through visualization. It is true that in some cases we obtained auditory filling but very often this was accomplished through preliminary visual filling. In other words, visual phenomena are so predominately operative in our mental life that auditory phenomena, when isolated, have a hard time of it in the production of perceptual complexes. Ordinarily, even in studies of sound localization, the objects are strongly visualized. When the two sounds are so discrete and objectively so unlike sounds that are produced from ordinary objects, there is a stronger tendency toward localization with its concomitant lesser tendency toward movement. It is possible, too, that, in the absence of a positive after-image analogous to that which occurs in the visual modality, the perception of motion is less likely.

[16] Ruckmick, C. A. The rôle of kinæsthesis in the perception of rhythm, *Amer. J. Psychol.*, 24, 1913, 305–359.

[17] DeGowin, E. L., and Dimmick, F. L. The tactual perception of simple geometrical forms, *J. Gen. Psychol.*, 1, 1928, 114–123.

So on the physical side it appears that the conditions are more naturally set for localization when the number of discrete stimuli is two or less and when the impulse of sound used is abrupt in the case of more than one impulse. Conversely the phi-phenomenon may find its optimal condition when the discrete sounds are continuous, that is, not abrupt, and when there are more than two presentations used.

The physiological situation is probably more complex than we have hitherto realized since in the purely auditory field, without the concomitance of visual cues, we are probably more neurologically set for sound localization with all its complex associative connections. Any theory of audition, and especially of sound localization, which is based primarily on the auditory mechanism will fail if it does not take into account a vast number of interconnections that must be involved in order to account for the variety of mental components, such as, attentive direction, the *Aufgabe,* racial tendencies, and effects of practice. In this the visual and motor tendencies must not be overlooked. The problem of accounting for all of the physical determinants, such as, temporal differences of arrival and the intensive, phase, and clang differences, is a very complex one from the analytical point of view. Actually, however, it is synthetic in aspect with the concurrent impossibility of introspective analysis. A picture is presented as a pattern and no matter how practised the observer is, he will probably be unable to analyze the components out of the pattern. The most that he will be able to say is that the sound appears to be different in its totality from place to place. On the mental side we are faced with the proposition of inherent cortical sets which may vary from time to time. The observer may at one time look for a sound that is localizable, at another time for one that is moving. The physical conditions which favor either one or the other of these situations may be determined. But, as in the field of illusion, we can not utterly neglect the mental attitude or the influence of attention in shifting from one aspect of the situation to another.

By way of summary, auditory localization involves, therefore,

not only favorable physical conditions but a definite mental set, an attentive attitude and an effect of practice which is commonly assumed but not usually recognized in our theoretical expositions. These critical attitudes while best induced by certain physical conditions can not be referred entirely to any sensory process but had better be explained in terms of neurological conditions in the cortex and underlying platforms as traces of past experience in the individual and in the race which interpret the present perceptual occurrence.

VARIATIONS IN THE GALVANIC RESPONSE[1]

by

FRANKLIN O. SMITH

I. Introduction. In experiments on the galvanic response certain characteristic variations occur which are of interest to the psychologist. These may be described in terms of the direction, latency, magnitude, time and number of deflections in a given response.[2] The primary object of the investigations reported in this paper was to determine the variations in each of these characteristics of the galvanic response when various stimuli are presented to different individuals.

The literature on the galvanic phenomena has been adequately reviewed in recent publications, and extensive bibliographies on the subject are available (5, 7). The results of recent studies insofar as they bear upon the present study may be summarized briefly in the statement that psychologists are generally agreed that the phenomenon is psychological or psychophysiological in character, but that opinion differs as to the precise character of the response. Bayley (3), Waller (9) and others have sought to demonstrate the relation between the galvanic phenomena and emotion. Aveling (2) and Bartlett (4) emphasize the conative indications of the response, while Abel (1) finds evidence which " seems to point to a fairly definite functional connection between electrical changes in the skin and certain reportable attitudes which mark sudden, decided and momentary checks in the course of the comprehension and the solution of simple problems of an elaborative sort." Thouless believes that the condition of low resistance is a condition of preparedness to react to a stimu-

[1] The investigation was carried on under the direction of Professor Christian A. Ruckmick.

[2] Other variables are the fore-period, or the interval between the instructions and the stimulus, and the after-period, or the interval following the maximum deflection or other limit which may be arbitrarily chosen.

lus. "A lowering resistance from the beginning of the observation," he says, "means that the subject is adapting himself to the requirements of the experiment" (8).

II. Procedure. The Hathaway apparatus was employed in the present study. In this apparatus the activating current is a 110-volt, 60-cycle, alternating current through an amplifying system. Since with the alternating current polarization and consequent change in potential between the electrodes is absent or negligible, this type of apparatus permits the use of metal electrodes attached directly to the palm of the hand.

Other advantages of the Hathaway instrument arise from the fact that the readings are in milliamperes and that the resistances in the primary and secondary circuits can be balanced quickly thus avoiding any delay in beginning the experiment. The instrument can be adjusted in a few seconds after the electrodes have been attached to *O*'s hand.[3]

A reader sat directly in front of the apparatus and traced the deflections of the indicator leaving *E* free to present the stimuli and observe the general behavior of *O*. The tracings were made by dotting in intervals of one to two seconds on appropriately ruled paper. The temporal intervals were indicated by means of an electrically driven chronoscope operating a telegraphic sounder.

Forty-nine *O*s including 18 men and 31 women participated in the experiments. Of these, 43 were students in advanced laboratory psychology and 6 were freshmen girls. Of the advanced laboratory class 8 were graduate students in psychology. Most of the experiments were made between 2 and 4 P.M.; the others between 9 and 11 A.M. In order to test the influence of diurnal changes in connection with the galvanic response some of the trials were repeated on the same *O*s on different days.

Each trial lasted 20 to 25 minutes and was divided into two parts, the first, a period of two minutes with no stimulus, and the second, a series of tests with various stimuli.

At the beginning of each trial, when the electrodes had been

[3] This apparatus has been described by *Hathaway* (6).

attached to *O*'s hand, but before the shunt had been switched on, the following instructions were given to *O*: "You must sit quietly and comfortably and be as composed and placid as you can. No stimulus will be presented and nothing will happen during this part of the experiment. Just relax and avoid moving your hands." A record was taken of the galvanic deflections for a period of two minutes.

In spite of the instruction to be composed and placid, some *O*s reported inability to make the required mental adjustment and to prevent certain associations suggested by the experimental situation which evoked a vague expectancy of something which they imagined might happen. A majority of the *O*s, however, reported "not disturbed," "quiet" or similar expressions.

At the conclusion of this no-stimulus period and after the response to each stimulus the Hathaway apparatus was switched off and *O* allowed to move freely. Before a stimulus was presented the instruction to sit quietly and be calm was repeated, immediately after which the apparatus was switched on, without *O*'s knowledge, and the stimulus presented.

Eight different stimuli and stimulating situations were included in the trials as follows:

1. F.Wt. An apparently heavy weight fell about 6 ft. directly over and to within 4 in. of *O*'s hand.
2. S.L.N. A sudden loud noise was made close behind *O*'s head.
3. T.Sn. A toy snake was seen wriggling from under a cover which was casually lifted by *E*.
4. El.Sh. A sudden electric shock from an induction-coil was applied to *O*'s hand, causing intense but vry brief pain.
5. Pch. The skin on *O*'s arm above the wrist was pinched smartly between *E*'s thumb and finger-nail.
6. M.M. *O* solved a problem in mental multiplication.
7. S.S.F.M. *O* listened for 20 sec. to the phonograph record, *Stars and Stripes Forever* March, played by an orchestra.
8. Aloha. *O* listened as before to *Aloha* played by Kreisler.

No definite method of presenting stimuli could be followed owing to differences inherent in the requirements of different situations. For the falling weight and the toy snake the eyes must be open; for the loud sound, the electric shock and the pinching they must be closed; for the others no special instruction on this point was given. Closing the eyes almost always

induced a feeling of expectancy, fear or anxiety. This was especially noted in the case of the electric shock which obviously was anticipated.

III. Discussion of results. The results of the responses during the no-stimulus period are presented in Table I. It will be noted that for 22 out of the 49 *O*s included in this table the initial deflection was to the right, indicating decreasing resistance to electrical currents between the electrodes, while for 27 it was to the left indicating increasing resistance. In all but 11 of these cases the deflection was wholly to the right or wholly to the left, never returning to the starting point. In the other 11 cases the deflections alternated between right and left of the starting point. Since the experimental conditions were approximately the same for all *O*s, these three types of deflection during the no-stimulus period may reasonably be interpreted to indicate temperamental and other differences in the responsiveness of the *O*s to the situation created by the instructions.

TABLE I

G.R. Without the Stimulus

No.	D	Mma	Rng	Tm	Rng	No Dfl	Rng
22	D R	.32	.08–.9	68	5–120		
						8	1–18
27	D L	.35	.06–.1	75	5–120		
11	D R L	.52	.05–.8	113	4–120	11	2–23

The first column presents the number of cases (No.) for each type of deflection.

In the other columns are represented, respectively, the direction of the deflections (D), maximum deflection in milliamperes (Mma), range of deflections for the group (Rng), time required for the maximum deflection (Tm), range of time for the group, and the number and range of deflections. The total time for each *O* was two minutes.

It will be noted that the average magnitude and time of the deflections to the left are slightly greater than those to the right. In the case of deflections alternating between right and left the total magnitude and time of deflection is obviously much greater than in the case of deflection in only one direction. The individual differences range between .05 milliamperes and 1 milli-

ampere for the magnitude and between 4 seconds and 120 seconds for the time. The number of deflections for all *O*s ranges from 1 to 23. A few sample curves were selected to represent typical variations in the no-stimulus period (see Fig. 1).

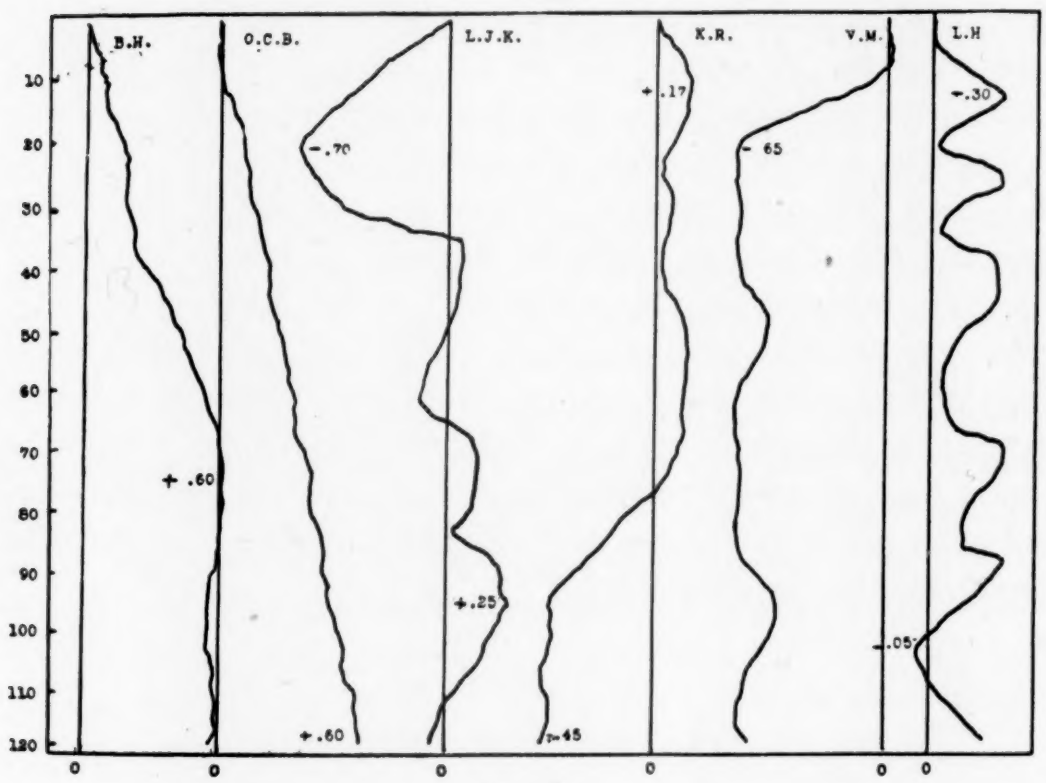

FIG. 1

Curves representing typical galvanic responses during a two-minute period without stimulus. The numbers at the left indicate time in sec. Those on the curves indicate maximal changes in resistance in hundredths of a milliampere. The direction of the change is shown by the plus or minus sign.

Before considering the results of trials with the various stimuli reference may be made to the question of the influence of diurnal changes on the galvanic response. In order to test this factor 23 of the trials without and with stimuli were repeated on different days in the case of 17 *O*s. Of these 23 repetitions 18 were in the same direction for both days. In two cases the trials were repeated on two different days and in both cases the direction of deflection was the same for the three days. The magnitude and time, of course, varied on different days, a fact which must be taken into account in evaluating the individual variations in these phenomena.

Table II represents the results of response to the various stimuli presented in these trials. Only four or five stimuli were presented in a given period and these were changed on different days which accounts for the limited and variable number of *O*s for different stimuli. The direction, latent time, magnitude, time, and number of the initial deflections for the various stimuli are discussed in their order.

TABLE II

	St.	No	D	LT	Ma	Rng	Tm	Rng	No Dfl	Rng
1	F.Wt.	17	R	1.9	.45	.05–.70	3.5	1–8	4	2–6
		11	L	1.6	.33	.07–.80	2.9	1–+10		
2	L.W.	17	R	1.6	.41	.05–.60	3.2	1–7	4	2–6
		14	L	1.4	.20	.05–.50	2.7	1–5		
3	Sn	18	R	1.9	.38	.06–.80	3.8	1–8	3	2–5
		10	L	1.4	.31	.10–.65	3.1	1–6		
4	El.Sh.	17	R	1.6	.40	.50–.70	3.3	1–6	3	2–5
		12	L	1.2	.33	.07–.45	2.7	1–5		
5	Pinch	23	R	1.7	.44	.05–.90	3.8	1–8	4	2–6
		5	L	1.6	.16	.07–.60	2.8	1–5		
6	M.M.	14	R	2.8	.38	.10–.65	1.2	1–+10	3	2–5
		9	L	2.2	.16	.07–.50	.5	1–10		
7	S.S.F.M.	12	R	2.4	.28	.05–.60	6.5	2–15	3	2–5
		4	L	2.1	.23	.05–.50	1.5	5–25		
8	Aloha	11	R	2.3	.25	.05–.50	.5	2–10	3	2–5
		5	L	2.3	.25	.05–.35	1.4	5–20		

The first and fourth columns give the stimuli (St) and latent time, respectively. The other columns are the same as in Table I.

(1) *The direction of the deflection.* This factor varies with individuals for all stimuli. Two classes of *O*s can be distinguished with respect to the direction of the deflection, namely a large number for whom the deflections are uniformly to the right and a smaller number for whom they are to the left for certain stimuli and to the right for others. In no case were the deflections for a given individual to the left for all stimuli. It will be noted that in approximately two-thirds of all cases the deflections were to the right when various stimuli are presented, whereas approximately the same proportion of cases exhibited the opposite tendency in the no-stimulus period.

(2) *The latent time.* The latent time of the galvanic response was greater when the deflection was to the right than when to

the left in the case of all stimuli except one (No. 8, Table II). The latency of response varies with the intensity of the stimulus, being shortest for the more intense stimuli (Nos. 2, 3, 4 and 5, Table II). It also varies with individuals between 1 and 4 or more seconds.

An attempt was made to determine the content of mental processes during the period of the latent time and the cause of the deflection by securing introspective reports immediately following the response and also by noting the behavior at the time of the stimulus. The following summary of the reports is fairly representative:

(a) *The falling weight.* Startle, mental excitement, and fear in varying degrees of intensity from very slight to very strong occurred; impulse to withdraw the hand or actually a withdrawing movement of hand and body appeared. In most cases there was only an impulse to move, but no actual movement. *O* was conscious of inhibiting the movement. Feeling of disgust at self arose for lack of control and feeling of amusement appeared; there was interest in the falling weight.

(b) *Sudden loud sound.* Startle, shock, and surprise occurred, varying from slight to very strong and complete. There was mental confusion and a tendency to jump. This was often followed by feeling of amusement.

(c) *Toy snake.* Sudden startle, usually strong in character, appeared. A complete surprise with some fright occurred. This was usually followed immediately by amusement and an impulse to withdraw. *O* often actually jumped back and had to "catch his breath". One said that he had impulse to grab the thing.

(d) *Electric shock.* *O* was completely surprised and frightened with a moderate to strong shock and mental confusion. There was an impulse to jerk the hand away with occasionally some fear. A very sharp pain was followed by feeling of relief. *O* was moderately surprised and amused, sometimes frightened, and jerked his hand away (right hand) with attendant mental confusion.

(e) *Pinching.* *O* was strongly surprised and felt slight resentment. Then he became moderately surprised and somewhat amused. He was moderately startled and jumped slightly. With the startle there was sometimes a cold chill. *O* became curious, was strongly resentful, and wondered why it was done.

(f) *Mental multiplication.* *O* was completely confused and slightly annoyed. There was consternation and difficulty in concentrating. He felt compulsion to hurry and had a slight tendency to speak the numbers. There was also a tendency to move his fingers as if performing the operations.

(g) *Stars and Stripes Forever March.* A strongly pleasing experience, exciting, with a tendency to follow the rhythm. *O* was conscious of inhibiting the tendency to keep time. There was motor imagery of playing in the band. The affective tone varied from moderately or mildly pleasing to indifferent.

(h) *Aloha.* A very pleasing experience, moderately or slightly pleasing to indifferent in affective quality.

In all the reports and observations certain phenomena stand out clearly. A strong unexpected stimulus causes surprise, startle or shock and often fear and mental confusion with an impulse to escape from the stimulus. These phenomena occur, as nearly as the *O*s are able to report the facts at the instant of, or immediately after, the stimulus. Slight movements of parts of the body other than the hand to which the electrodes are attached (left hand) apparently do not affect the galvanic deflection appreciably unless accompanied by other phenomena such as startle, fear, or mirth. In this connection it is of interest to note that in the case of mental multiplication the latent time is relatively long while the reports revealed a number of cases of mental confusion, impulse to hurry, *etc.* In the majority of cases, however, no such mental upsets were reported. Furthermore, the stimulus lacked the suddenness and unexpectedness that was found in the other cases mentioned above.

Any attempt to discover the cause of variations in the deflection which indicate changes in resistance must take account of those conscious and semi-conscious reactions of *O* which occur between the stimulus and the beginning of the deflection. That the immediate cause is not the slight involuntary movements and impulsions to withdraw the hand, *etc.,* is shown by the fact that the time required for their occurrence is much less than the period of latency, a fact observed also by *Thouless and others.* These involuntary movements have disappeared and apparently have been superseded by a conscious effort to recover the mental calm required by the instructions, when the deflection has once begun.

The observations and introspective reports seem to present evidence in favor of the view that the content of the latent time which operates as an exciting cause of the deflection is a mental re-organization and re-adjustment to the experimental situation following close upon the emotional upset and mental disorganization produced by the suddenness, unexpectedness, or insistence of the stimulus. This manner of interpreting the facts will account for the period of latency and its variation with individuals.

(3) *Magnitude and time of deflection.* Both magnitude and time of the initial deflection vary with the direction of the deflection, the character of the stimulus and peculiarities of the individual. The average magnitude is greater for every stimulus but one (No. 8, Table II) when the deflection is to the right than when it is to the left. The responses of greatest magnitude are evoked by stimuli which, in accordance with the introspective reports, cause the greatest mental disorganization, shock or startle, such as the falling weight, pinching, the loud sound, the electric shock, and the toy snake. Mental multiplication ranks next in order for the average magnitude but it must be remembered that in this case the time during which the stimulus may be said to operate was much longer (15 to 20 sec.) than in the case of the other stimuli just mentioned.

The time varies in the same manner as the magnitude except for the musical records (Nos. 7 and 8, Table II). It will be noted that the time in these two cases is much longer for deflections to the left than for deflections to the right. No special importance can be attached to the exceptional cases of numbers 7 and 8, partly because of the insufficient number of *O*s and partly perhaps on account of the wide range of individual responses to a particular musical selection.

A considerable range of individual differences is revealed in both the magnitude and the time. In the case of the falling weight (No. 1, Table II), for example, the magnitude varies between .05 ma. and .80 ma. in a group of 28 individuals. The time likewise varies between approximately 1 sec. and over 10 secs. These facts undoubtedly represent fundamental differences in temperamental, conative or other tendencies which are indicated by the direction, latency, magnitude and time of the galvanic response.

(4) *The number of deflections.* In determining the number of deflections only appreciably permanent changes in the direction of the indicator were taken into account and not the minor fluctuations occurring while the indicator was progressing, or returning, in the same general direction. The average number

of deflections in a period of 20 sec. is nearly the same for all stimuli but shows a fairly wide range of individual difference.

There is, moreover, a greater variability of responsiveness than

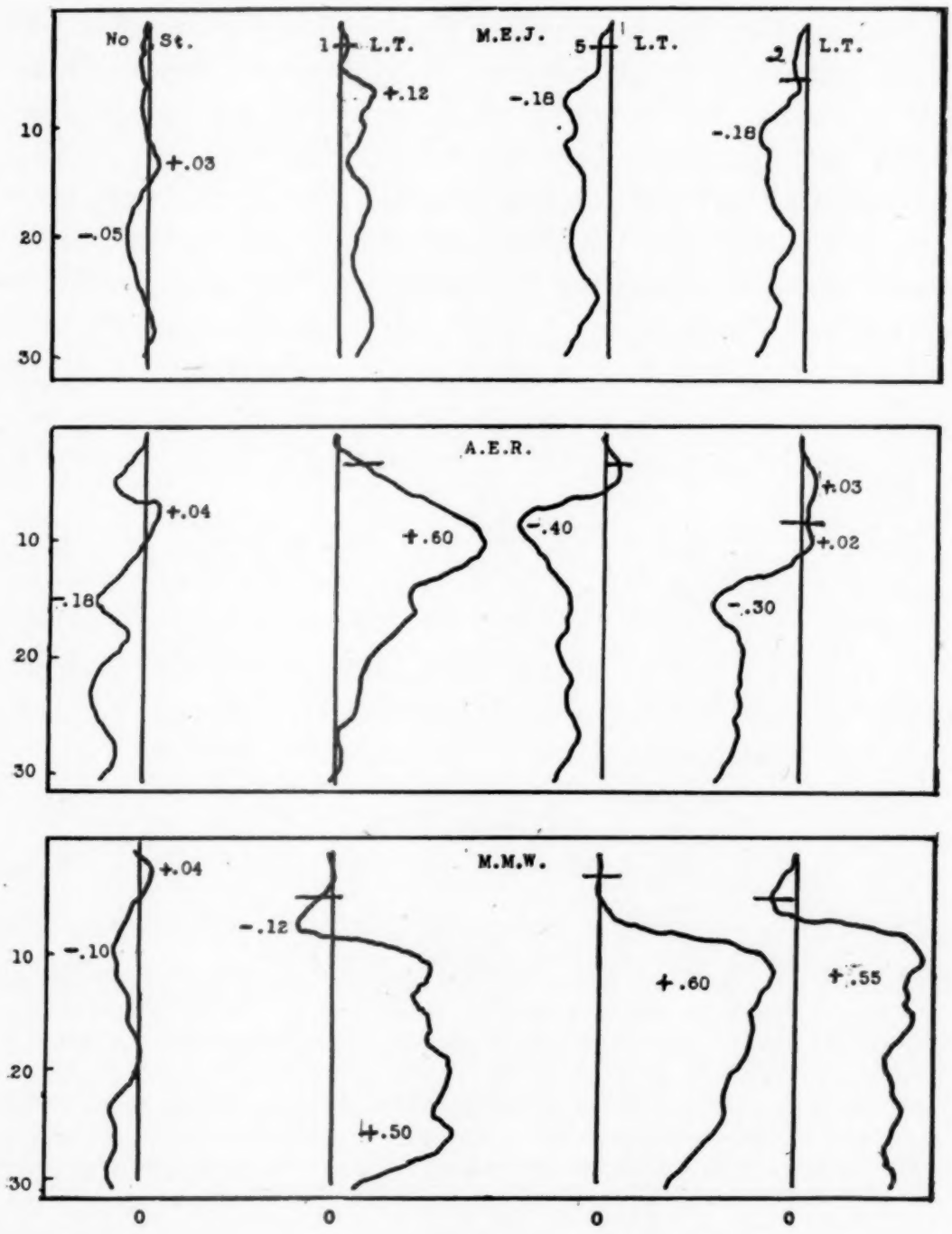

FIG. 2

Curves representing the galvanic responses of three *O*s, M.F.I., A.E.R., and M.M.W., in the no-stimulus period and to three different stimuli, namely, 1 F.Wt., 5 Pch., and 2 S.L.N. Numbers indicate time and change of resistance as in Fig. 1; L.T. means latent time for the three stimuli respectively.

is exhibited by the data presented in the table. No two actual curves were alike in all details. In one the deflection started from a brief latent time, moved quickly across to the maximum and returned as quickly to the starting point. In a second the movement started more tardily and proceeded slowly and steadily to the maximum where it remained for a period varying from a few seconds to half a minute or more and then returned slowly to the starting point. In a third the indicator moved by short forward and backward deflections gradually reaching the maximum and returning in the same fluctuating manner to the starting point. In another case the movement was first to the right (or left) of the starting point by any of the methods just described and then it swung back to the opposite side of the scale and finally came to rest at the starting point. Many other individual idiosyncrasies may be noted in the curves but these are perhaps typical.

Not only do the deflections vary with different *O*s for the same stimulus, but the same *O* may show different galvanic responses to the same stimulus on different occasions. These may vary in direction latency, magnitude or time of deflection. Fig. 2 presents sample curves from the records of three *O*s which illustrate these variations.

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SOME ASPECTS OF THE PSYCHOPHYSICS OF THE VIBRATO[1]

by

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I. INTRODUCTION

1. *The nature and significance of the vibrato.* The vibrato may be roughly defined as the rapid pulsating effect heard in singing. *Metfessel* (15) has found this effect present in 95 per cent of the tones of accepted artists. In spite of the almost universal presence of the phenomenon in the voices of accepted vocalists its exact nature has only recently been the subject of scientific investigation.[2] Of the recent investigators, *Metfessel* (16) probably gives the most authentic description of the vibrato employed by vocal artists. He maintains that "the artistic vibrato may be partly described in terms of the sound-wave as a cycle of frequency[3] with . . . an average extent[4]

[1] Grateful acknowledgment is made to Dean C. E. Seashore, who directed this study.

[2] A number of experimental studies on the nature of the vibrato have recently been made by *Schoen* (18), *Kwalwasser* (11), *Metfessel* (16), *Easley* (6), *Tiffin* (23), *Hollinshead* (10), *Gray* (8), and *Shimmick* (21). In addition to these an exhaustive monograph on the subject is now being prepared by Metfessel.

[3] It will be noticed that *Metfessel* describes the vibrato as a fluctuation in frequency, not as a fluctuation in pitch. It is necessary in studies which deal both with the sound-wave and the auditory experience to distinguish between frequency and pitch and between energy and intensity. The reason for this is that the pitch heard does not always follow the frequency of the sound-wave. In order to avoid confusion the terms frequency and energy will be used in this study when reference is being made to physical instruments or to the sound-wave, whereas pitch and intensity will be used when the reference is to the auditory experience. The term *energy* will refer to the transmission of energy per unit time in a unit wave-front.

[4] By *extent* of the vibrato is meant the difference between the highest and lowest frequencies reached in the fluctuation.

of a half-step,[5] ranging from a fifth to more than a whole step from tone to tone; [and] an average rate of approximately seven cycles per second, ranging from 5.5 to 8.5 from tone to tone." *Hollinshead* (10) has shown that the artistic violin vibrato also has an average rate of about seven pulsations per second but that its average extent is only about .25 of a step. The artistic vibrato also usually exhibits a small fluctuation of energy, but the energy factor is not as significant as the frequency factor.[6]

2. *Statement of the problem.* The method of approach of the experimental work already done on the vibrato has consisted mainly of photographing the sound-wave from singers, speakers and instrumentalists, measuring the fluctuations in frequency, and deducing norms which indicate the type of vibrato actually employed by various types of singers, speakers or players. This is a type of psychophysics which, in *Seashore's* (20) terminology, " measures the output." The only attempt so far made to apply the older type of psychophysical approach to the vibrato, *i.e.*, to control the stimulus and determine what is heard, is that of *Metfessel* (13, 14). He showed that, in synthetic vibratos produced by means of siren discs, the quality of a tone is determined not only by its wave-form but also by the characteristics of its vibrato. He introduced the term *sonance* to describe that part of the quality of a tone which is due to the successive fusion of waves of the same form. The vibrato is thus a special type of sonance. *Metfessel* also states (15) that " a vibrato at a rate of seven times per second and an extent of a half-step is not a rise and fall of pitch in such a situation. . . . The variations fuse and produce an effect that is beautiful and unique. . . .

[5] For various reasons it is convenient to speak of the extent of the vibrato as a fraction of a musical step rather than as a frequency fluctuation of so many vibrations. Since the extent of the vibrato is a purely physical concept, the term musical step will be used in the physical sense to refer to a ratio of 1.122: 1 between frequencies. The corresponding phenomenological interval of pitch will be referred to as a musical tone.

[6] Although several attempts have been made [*Cf.* (11) and (22)] to determine whether the artistic vibrato contains a fluctuation of energy, no conclusive results have been published. The statement made above is based on an analysis of the energy factor now being made by the writer. It is shown in the present study, however, that an energy vibrato can be produced synthetically which will closely simulate a frequency vibrato.

The tonal mass has one salient pitch at its focus." He also states (14) that the perceived pitch of a frequency vibrato is located at the mean physical frequency. He has not yet published experimental material, however, in support of the above conclusions.

The work reported in this paper is the result of an attempt to apply the traditional psychophysical approach to the vibrato. Specifically, answers to the following questions were sought:

1. What is the smallest frequency vibrato which can be heard and recognized?
2. What is the smallest energy vibrato which can be heard and recognized?
3. What is the effect on the threshold for perception of the vibrato when a frequency and an energy vibrato are combined in different phase relations?
4. Does the ability to hear a frequency vibrato differ with different individuals? If so, is there any correlation between ability to hear a frequency vibrato and pitch discrimination?
5. Does the ability to hear an energy vibrato differ with different individuals? If so, is there any correlation between ability to hear an energy vibrato and intensity discrimination?
6. Is the threshold for vibrato perception different in different regions of the scale?
7. Is the threshold significantly different for vibratos of different rates?
8. Does the ear follow the fluctuation in frequency in a frequency vibrato or does the fluctuation occur so fast that the fluctuating frequency is fused in perception into one salient pitch?
9. If such a fusion takes place, does it change its characteristics when the extent or rate of the vibrato is changed?

II. Apparatus

1. *General description.* Before the problems outlined above could be effectively attacked it was necessary to develop an apparatus for the synthetic production of vibratos. The qualities desired in such an apparatus were that it allow independent variation of (a) the extent of the fluctuation in frequency, (b) the amount of the fluctuation in energy, (c) the number of vibrato pulsations per second, (d) the frequency-energy phase relationship and (e) the form of both the frequency and energy fluctuations. While there are a large number of standardized laboratory instruments available for the production of sound, most of these were found to be little suited to the production of a vibrato with the above mentioned factors under adequate control. Hence

the first problem encountered was the construction of a suitable apparatus.

The apparatus finally adopted [7] consisted essentially of a siren disc, except that the disc intercepted a beam of light shining on a photo-electric cell instead of the customary blast of air. A schematic drawing of the apparatus is shown in Fig. 1, and a photograph of the arrangement in Fig. 2. The rotating drum weighs approximately 8.5 kg. and is exactly counterbalanced. This drum had been used by *Metfessel* (**13, 14**) in some previous experiments. The discs were made of tough cardboard and were held on top of the drum by a counterbalanced cast-iron plate. Both the plate and the discs were clamped to the main drum by

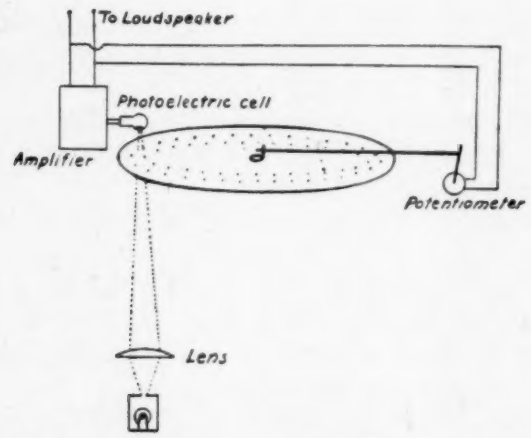

FIG. 1. Schematic drawing of synthetic vibrato apparatus

means of a large central nut. The diameter of the cardboard disc was several centimeters greater than that of the drum, mak-

[7] Two devices were constructed which, although satisfactory for demonstrating the various forms which the vibrato may take, could not be used in work of high precision. The first of these consisted of a pipe, similar to an organ pipe, enclosed in a partially sound-proof box and blown by compressed air. The frequency of the sound was varied by an oscillating movement of the plunger of the pipe, and the energy of the sound emitted by a sliding door in the side of the box. The rate of the fluctuations in frequency and energy could thus be changed by changing the rate of movement of the plunger and the door. This device could not be used because the frequency of the sound produced could be only roughly controlled. An attempt was also made to use a vacuum tube audio-oscillator. The circuit used by *Hauge* (**9**) was employed. In order to produce a frequency vibrato a device was constructed by means of which the capacity of the oscillator circuit could be rapidly varied. Although this apparatus produced an excellent vibrato, the frequency of the oscillator changed from time to time in such a way as to make the apparatus unsuited for psychophysical work.

ing it possible to drill as many as eight rows of holes, thus producing eight different tones, on a single disc. A lens was used to bring the light, whose source was about 60 cm. below the disc, to an approximate focus at the disc, the beam of light passing

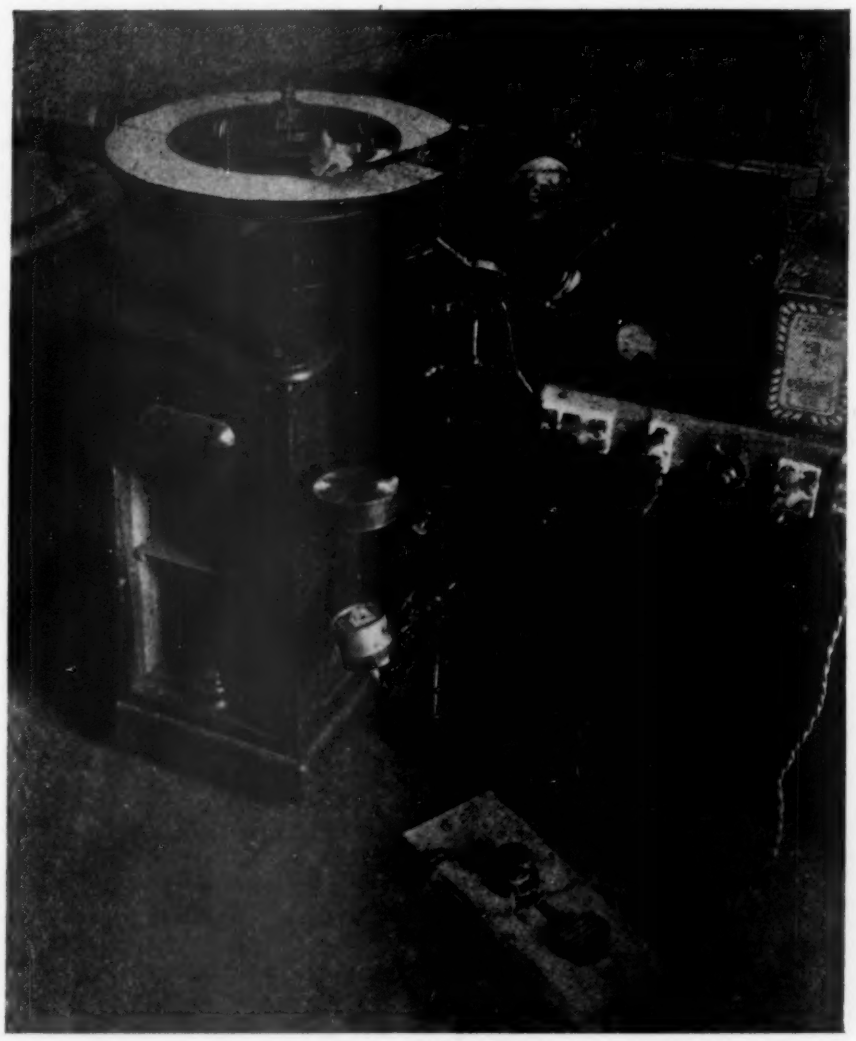

FIG. 2. Photograph of synthetic vibrato apparatus

through the holes so as to shine on the photo-electric cell.[8] The latter was located about 2 cm. above the disc. The light, lens and photo-electric cell were mounted on a single swivel so that a quick change could be made between any of the rows of holes on a single disc. The photo-electric cell was connected to the

[8] A G-M Visitron No. 72 photo-electric cell was used throughout the work and found satisfactory. This cell is manufactured by the G-M Laboratories, Chicago, Ill.

input of a four stage resistance coupled amplifier. The latter was calibrated over the frequency range 300 ~ to 450 ~ and found to have an approximately constant characteristic within this region. The amplifier was operated entirely on direct current

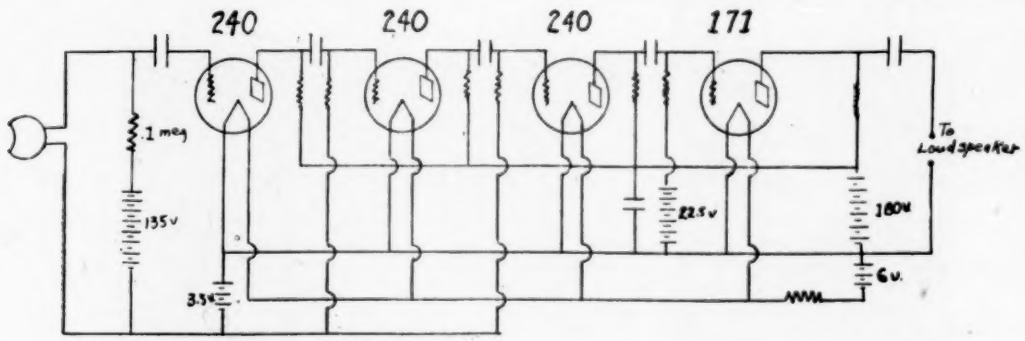

FIG. 3. Diagram of amplifier used with photo-electric cell

from batteries to avoid the possibility of alternating current distortion. A diagram of the amplifier is shown in Fig. 3.

The drum and disc were rotated by a Galvin constant speed motor greared down so that the drum could be turned 5, 6, 7, 8 or 9 revolutions per second. The motor and gear box are shown in Fig. 4. The constancy of the frequency of the sound-waves

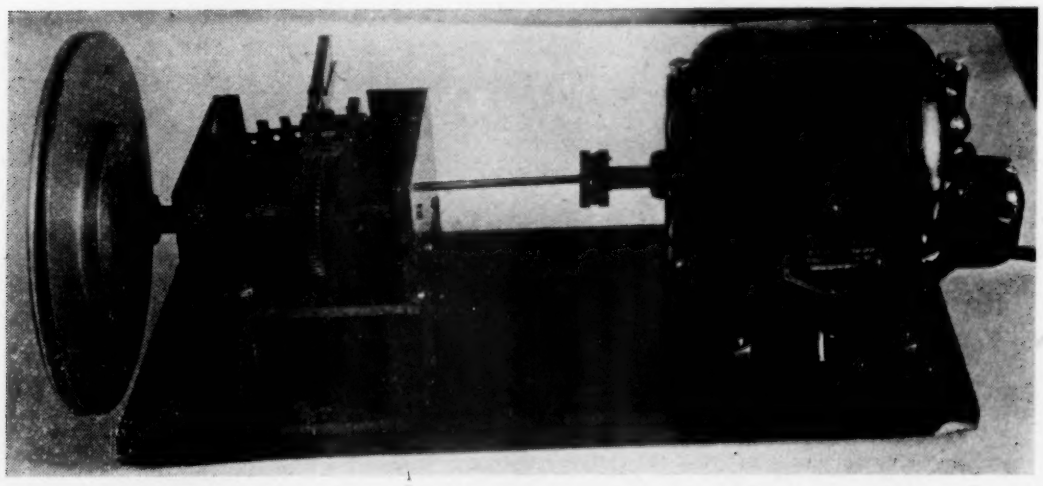

FIG. 4. Photograph of motor and gear box used to operate synthetic vibrato apparatus

produced by this apparatus was carefully checked in two ways. First, a wave of constant frequency, 420 ~ produced by the apparatus was caused to beat against a tuning fork differing slightly in frequency. By repeatedly counting the number of

beats in a given interval of time the accuracy of the apparatus was determined. No fluctuations in frequency greater than .5 ~ were found. The tone produced by the apparatus was also read on the Seashore tonoscope (large model). No fluctuations of frequency greater than .5 ~ could be detected on this instrument.

2. *The production of the frequency vibrato.* It can be seen that if the holes on one side of the disc are slightly closer together than those on the other side, a frequency vibrato will be produced. The frequency of the sound wave will be higher when the closely spaced holes pass the photo-electric cell than when the more widely separated holes pass this point. The number of vibrato pulsations per second will be determined by the number of revolutions of the disc in a second. Since the average vibrato of artists occurs at a rate of about seven pulsations per second, this vibrato rate was accepted as standard.

If there are 60 equally spaced holes in the circumference of a disc, *i.e.*, if the holes are placed six degrees apart, a frequency of 420 ~ will be generated when the disc revolves seven times per second. Because of the proximity of this frequency to A of 435 ~ and also because of the convenience of a six degree separation of the holes as a base, 60 holes in a circumference was accepted as standard. Drilling the holes closer together on one side of the disc than on the other would thus cause a fluctuation in frequency about a central frequency of 420 ~. The absolute extent in frequency of the vibrato thus produced could be controlled to a very high degree of accuracy since the holes in the disc were very carefully drilled. The discs used were all drilled while mounted in a dividing engine which was accurate to one-tenth of a minute. Schedules were prepared showing the exact separation of the holes in degrees and minutes for each vibrato. From the calculations for the hole spacing at 420 ~ the spacing for 210 ~ can be easily obtained by multiplying all inter-hole spacings by two. Also, by dividing all inter-hole spacing by two, the schedules for a mean frequency of 840 may be obtained. Following this scheme, discs in three scale regions can be prepared with minimal labor from schedules prepared for one region.

For the psychophysical work in which the method of constant stimuli was used it was necessary to have several vibratos whose extents expressed in absolute frequency formed an arithmetic series. This was accomplished by drilling a disc containing five rows of holes so that when run at seven revolutions per second the extents of the five vibratos produced would be .5, 1.0, 1.5, 2.0 and 2.5 ~ per second. In other words, in the smallest vibrato the lowest frequency reached would be only .5 ~ per second lower than the highest frequency reached; in the next vibrato the lowest frequency would be 1.0 ~ per second lower than the highest frequency, *etc.* Once constructed, this disc could also be used at four, five, six or eight revolutions per second by taking cognizance of the fact that the common difference between frequency extents of adjacent vibratos becomes less when the speed of the disc is decreased and greater when it is increased. For any given speed, however, the extents of the vibratos produced will differ from each other by a common amount in frequency extent.

For the group experimental work, in which no theoretical curves were fitted to the empirical data, the vibratos were expressed in fractional parts of a step in the musical scale. For the purpose of drilling the discs for this part of the work it was necessary to determine the absolute limits of frequency of vibratos whose extents were to be certain specified fractions of a step. The interval between C = 258.65 ~ and D = 290.33 ~ was considered one full step. The interval between C = 258.65 ~ and C♯ = 274.03 ~ was thus a half-step and in the tempered scale there are twelve such half-steps in the octave. Since the ratio of two frequencies an octave apart is 2:1, the ratio of any frequency to the frequency a half-step below it must be $2^{\frac{1}{12}}:1$, and the ratio of any frequency to the frequency one whole step below it must be $2^{\frac{1}{12}\cdot 2}:1$ or $2^{\frac{1}{6}}:1$.

Taking the ratio $2^{\frac{1}{6}}:1$ as the fundamental ratio, *i.e.*, the ratio of two frequencies separated by one musical step, the ratios of

frequencies separated by .05 of a step, .1 of a step, *etc.* are obtainable directly from it by extracting further roots. Thus: ratio of frequencies separated by .05 steps is $2^{\frac{1}{6}\cdot\frac{5}{100}}$: 1 or 1.0058.

After securing the necessary ratios in the manner described above, Table I was constructed. This table shows in the left column the deviations in fractions of a step above and below 420 ~ and in the right column the frequencies corresponding to each fractional deviation.

TABLE I. *Frequency of fractional parts of a step above and below 420 ~*

Fractional part of a step above or below 420 ~	Frequency
.25	433.0
.22	431.7
.20	430.4
.15	427.8
.12	426.5
.10	425.2
.05	422.6
.00	420.0
.05	417.4
.10	415.0
.12	413.8
.15	412.6
.20	410.2
.22	409.0
.25	407.8

By dividing all the figures in the right column of Table I by two, the fractional parts of a step above and below the frequency of 210 ~ may be secured. In like manner, if the figures are multiplied by two, the result will be fractions of a step above and below 840 ~.

To drill a disc for example, which will produce a vibrato of .2 of a step, it is only necessary to determine from Table I the frequency of the tone which is .1 of a step above 420 ~ and the frequency of the tone which is .1 of a step below 420 ~. A vibrato .2 of a step in extent should oscillate between these extremes. It will be noticed that .1 of a step above 420 ~ is 425.2 ~ and .1 of a step below 420 ~ is 415 ~. The vibrato

in question should thus fluctuate in frequency between the limits 415 and 425.2 ~ per second.

Unless otherwise noted, the discs were all drilled so that in the vibratos produced the frequency (absolute) is a sine function of time.[9] This was accomplished by looking up in a table of natural sines the value of the sine at each point of rotation of the disc and separating the holes at that point so that the fluctuation in frequency would follow a sine curve. For example, in the above illustration the mean frequency must be at 420 ~, the maximum frequency at 425.2 and the minimum frequency at 415 ~. The difference between the mean and the maximum in this case is 5.2 ~. For the first hole the value of the sine is zero, so two holes were drilled six degrees apart. At six degrees the value of the sine is .10453. Hence the next hole should be so spaced that the frequency which will be produced at this point is 420 ~ + .10543 (5.2) ~ or 420. 5 ~. It is then necessary to compute the number of degrees and minutes between holes necessary to produce a frequency of 420.5 ~. Remembering that the disc rotates seven times per second, the spacing of holes for any given frequency is given by the following formula, where D represents the distance between holes expressed in degrees and F represents the given frequency.

$$D = \frac{7(360)}{F}$$

The decimal part of D must then be transferred into minutes and fractions of a minute before the dividing engine can be used to space off the hole. In practice the exact spacings for all the holes on a disc were computed and arranged into schedules before the actual drilling was begun.

By plotting the increment of frequency in this manner so that it follows the value of a sine function it will be seen that

[9] The exact form of the artistic vibrato has not been accurately determined. On the basis of a large number of records taken from artistic singers, however, the generalization made by Seashore (20) that the fluctuation takes the "form of a smooth sine curve" is probably justified. While the artist does not produce a fluctuation which rigidly adheres to any mathematical function, the sine curve is probably a close approximation to the "generalized" artists' form.

the holes get closer and closer together until the 90 degree point is reached, whereupon they begin separating until 270 degrees is reached, and that at this point they again begin getting closer together until, when the 360 degree point is reached, the inter-hole spacing is the same as at the beginning of the revolution. The vibratos thus produced have a gradual increment or decrement of frequency at all points and there is no jump in frequency due to the fact that the holes in the disc do not come out even when the circumference is completed. It is of utmost importance to have the holes "come out even", as it were, in threshold work, for if there is a space between the last hole and the first hole which is slightly different in size from the spaces between adjacent holes, a periodic noise will be produced which *O* may report as a vibrato. All the discs prepared were carefully checked for this error and those in which it was found were immediately discarded. In one part of the work, namely the determination of the pitch heard in a vibrato, it was necessary to have the discs produce tones of constant frequency in addition to the vibratos. For tones of constant frequency the holes must all be equally spaced and in such rows there was usually an irregular space left between the last and the first holes. The result of this was a slight periodic noise. Since the constant frequencies were used however, merely for comparison of pitch, and since the pitch was always very prominent in spite of the periodic noise, the presence of the latter was only a slight disadvantage.

The factor of fluctuations in wave-form in the vibratos produced by the apparatus should be mentioned at this point. The process of producing the frequency vibratos by drilling holes closer together on one side of the disc than on the other also produced a slight fluctuation of wave-form, for, since the diameter of the holes was constant, placing the holes closer together changed the relation between duration of the crest and duration of the trough in the sound-wave produced. This fluctuation of wave-form should theoretically have produced a fluctuation of the qualitative attribute of sound which *Abraham* (1) called "brightness" but which, since it is determined by wave-form, might better be considered as a special type of timbre.

In order to determine whether the fluctuations of wave-form thus produced are psychophysically significant, a disc was constructed containing two concentric rows of holes. The rows were of such diameters that the two waves produced by them would differ from each other in their trough-crest relation by an amount equal to the difference in trough-crest relation between the extreme frequencies of a vibrato 40 ~ in extent. It was assumed that if the timbre or "brightness" difference between the tones produced by these two rows is imperceptible, the factor of timbre or "brightness" fluctuations in the vibratos produced might be considered negligible.

A short series was run in which five *O*s were presented with 100 pairs of tones. Fifty pairs consisted of two consecutive tones from the same row and 50 pairs consisted of a tone from each of the two rows. The *O*s were instructed as follows:

"You will hear a number of pairs of tones. After each pair you are to judge whether or not there was any difference in quality or brightness between the two tones of that pair. If you heard a difference, record D. If you did not hear a difference, record S. Listen carefully and if you hear any difference, however slight, record D."

Four of the five *O*s were also used in the main body of intensive experimentation.

The *O*s were expected to get 50% of their judgments right by chance. Hence, unless percentages of correct responses significantly higher than 50 were obtained, it is safe to assume that the slight difference in wave-form between the tones produced by the two rows does not operate to produce a difference in timbre or "brightness" which is psychophysically significant. The obtained percentages of correct responses for the five *O*s were 49%, 54%, 44%, 59%, and 48%. Of these percents, 59 is the farthest from 50. Even in this case, however, the difference between 50 and 59 is well within the limits of sampling error if the true percentage is really at 50. Hence, since none of the percentages differ significantly from 50, it is quite safe to assume that the fluctuations in wave-form produced by the frequency vibratos are not psychophysically significant.

3. *The production of the energy vibrato.* Energy vibratos were produced in two ways. One method was to vary the size of the holes in the disc so that the holes on one side were larger than on the other. Assuming that the energy in the wave produced is proportional to the amount of light shining on the photo-electric cell, an energy vibrato is thus produced, the amount of the fluctuation in energy being determined by the difference in size between the largest and smallest holes in the row. This method was employed where it was desired to have a standardized series of energy vibratos graduated in the amount of their fluctuation and quickly interchangeable.

The other method of producing an energy vibrato consisted in shunting a potentiometer of very high resistance across the output of the amplifier and oscillating the resistance of the potentiometer by means of a light wooden rod connected to a small crank-shaft in the center of the drum. This technique made it possible to superimpose a fluctuation in energy on the discs already prepared for frequency vibratos. The phase relation of the fluctuations in energy and frequency could be easily altered and the extent of the fluctuations in frequency and energy could be independently varied.

4. *Experimental setting.* The apparatus was located several rooms away from the *O*s so that the noise of the machinery could not be heard. The tones produced were presented to the *O*s through a cone loud-speaker. A foot pedal was connected so that the output of the amplifier was automatically short-circuited except when the pedal was depressed. The procedure of presenting the tones consisted in swinging the beam of light and photo-electric cell until the correct row of holes was intercepting the light. The foot pedal was then depressed for the period of time it was desired to present the tone to the *O*s. A metronome was used for controlling the duration of each tone presented as well as the interval between tones.

A separate circuit was instituted to maintain telephone communication between *E* and *O*. In the intensive series the *O*s were situated in a sound proof room. Each *O* was seated in a

chair provided with a writing arm. Beaver-board partitions were erected between *O*s to prevent the possibility of mutual influence or suggestion.

III. The Extensive Series.[10]

1. *Introduction.* It is obvious that completely satisfactory answers to the questions outlined at the end of the first section could be obtained only from experimentation involving a comparatively large number of subjects.[11] Indeed, those questions involving norms can not be answered at all except in the light of group-experimentation. It is possible, however, that a fairly satisfactory answer to such questions as the sixth to the ninth may be obtained from intensive experimentation upon a much smaller number of *O*s. Whether or not it is ever theoretically desirable to draw conclusions which are based on a small number of *O*s it is certainly out of the question on practical grounds to do otherwise in an intensive psychophysical experiment. The intensive approach can not be abandoned for this reason, however, for it has one great advantage over group-experimentation, namely, its results approach mathematical exactness in the measurements made upon the *O*s used.

In this experimental work an attempt was made to strike a medium between these two types of approach. For the normative material and intercorrelations of various test results, several hundred subjects were used. For the work in which we desired to approximate true psychophysical thresholds as closely as possible, five *O*s were used and a rigid psychophysical procedure was followed. In this section the group-experimentation, or extensive series is described. In the following section the results of the intensive series will be given and in the final section a summary of the results as a whole will be given.

2. *The group-tests.* Two group-tests were constructed, one being a test of ability to hear a frequency vibrato and one a test

[10] An *extensive* series is one which secures gross data for a large number of subjects. An *intensive* series secures the most precise data possible for a small number of subjects.

[11] To avoid confusion, the term *subjects* has been arbitrarily used in referring to the extensive series and "*O*s" in referring to the intensive series.

of ability to hear an energy vibrato. The frequency vibrato test will be described first. A disc was prepared containing six rows of holes, the holes in each row being so spaced that the following tones were produced when the disc was revolved seven times per second.

Row	Tone	Frequency limits
1	Constant frequency at 420	
2	Frequency vibrato .02 steps in extent	419.3–420.6
3	" " .05 " " "	418.7–421.3
4	" " .10 " " "	417.4–422.6
5	" " .15 " " "	416.2–423.9
6	" " .25 " " "	413.8–426.5

The above range of frequency extents, *i.e.*, from .02 of a step to .25 of a step, was decided upon after considerable preliminary experimentation. This preliminary work indicated that even a very good ear could not always hear a vibrato as small as .02 of a step in extent, whereas a vibrato .25 of a step in extent is usually apparent to everyone. It therefore seemed that a test constructed over this range would cover normal differences of ability. The test consisted of 200 tones, 100 of which were of constant frequency at 420 ~ and 100 of which contained a vibrato varying in extent from .02 to .25 of a step. The vibrato tones were equally distributed on the five extents given above, there being 20 vibratos on each level of difficulty or extent. The tones were presented in serial groups and double fatigue order, starting and ending with the easiest, the more difficult being placed in the middle of the test. Thus the first 20 tones presented consisted of tones of constant frequency at 420 ~ and vibratos .25 of a step in extent, mixed in random order. The 21st to the 40th tones consisted of straight tones and vibratos .15 of a step in extent, *etc.* The 81st to the 120th tones were the most difficult to distinguish, consisting of straight tones and vibratos only .02 of a step in extent.

For the purpose of securing data on the reliability of this test, another form, Form II, was constructed. Form II differed from Form I only in the order of presentation of the tones within the single columns. The two forms were identical in content. The tones were presented at the rate of 20 per minute, *i.e.*, each

tone lasted 1.5 seconds with an interval of 1.5 seconds between tones.

The purpose of the experiment was to have the subjects distinguish between the vibratos and straight tones. The instructions were as follows:

> "A vibrato is a rapid pulsation occurring seven times per second. In this experiment you will hear a number of tones and after each tone you are to record whether or not you could hear a vibrato in that tone. If you heard a vibrato, record plus. If you did not hear a vibrato, record minus. Begin with column A. Fill column A first, then go to column B, then to C, *etc*. Listen carefully but do not expect that every tone presented will have a vibrato. Half of the tones will not have a vibrato. There will be a very short rest after each column is filled."

Before the test was begun a number of examples of tones with a vibrato and tones without a vibrato were given. Oral responses were called for in order to be sure that all the subjects knew exactly what they were to listen for and how they were to record their judgments.

The test of energy vibrato was similar to the test of frequency vibrato except that each form of the test of energy vibrato consisted of 240 tones instead of 200. A disc was prepared with seven rows of holes. Each row was composed of holes separated from each other by exactly six degrees so that no fluctuations of frequency were produced. The size of the holes in each row was varied so that an energy vibrato would be produced by all of the rows except one. The prominence of the energy vibratos thus produced was graduated so that the smallest was barely perceptible whereas the largest was quite marked. This disc was drilled in tin so that a standardized set of B. & S. drills could be used to insure an even increment and decrement of energy. Table II shows the number of the drill used and the diameter in thousandths of an inch for the largest and smallest holes in each row.

The tones in this test were also presented in serial groups and double fatigue order, half the tones being of constant energy and half containing energy vibratos distributed equally on the six steps indicated in Table II. Forms I and II of this test

differed from each other only in the order of presentation of the tones in the separate columns.

The instructions to the subjects were exactly the same for tests of both frequency and energy vibratos. The subjects were simply asked to listen for a pulsating tone. It was pointed out by *Schoen* (18) and corroborated in this study (*Cf.* the intensive series) that even experienced introspectionists find it very difficult if not impossible to distinguish between a frequency vibrato and an energy vibrato. All that is heard is a periodic pulsation. In view of this fact it was felt that it would only be confusing to attempt to explain the difference to a class of students in elementary psychology. The judgment is also much easier to make if only a pulsating effect must be identified.

TABLE II. *Variation in the size of holes in the disc used for the test of energy vibrato discrimination*

	Largest hole		Smallest hole	
Row	Drill No.	Diameter	Drill No.	Diameter
1	20	.161 in.	20	.161 in.
2	19	.166 "	21	.159 "
3	18	.169 "	22	.157 "
4	16	.177 "	24	.152 "
5	12	.189 "	28	.140 "
6	8	.199 "	32	.116 "
7	1	.228 "	40	.098 "

For scoring the tests keys were constructed similar to those used by *Larson* (12). "+" was considered the correct response to any vibrato at all, however slight, and "—" was considered the correct response to straight tones. The score of any individual consisted simply of the number of correct responses.

3. *Administration of the tests.* The group-experimentation was conducted with the elementary psychology class at the University of Iowa. The tests were given to this class on Dec. 9, 1929. Dr. L. W. Miller assisted with their administration in as much as it was necessary for *E* to be in the laboratory operating the apparatus. The loud-speaker and telephone were carried into the auditorium in which the lecture sections of the elementary psychology class meet. By means of the telephone, Dr.

Miller was in communication with *E* during the entire course of the experiment.

The class referred to met in three sections, at 9:00 A.M., 11:00 A.M., and 2:00 P.M. In the 9:00 A.M. Section, Form I of the test of frequency vibrato was given first. As soon as this was completed, Form I of the test of energy vibrato was given, upon the completion of which Form II of the test of frequency vibrato was given. All the members of the 9:00 A.M. section thus took both forms of the test of frequency vibrato and one form of the test of energy vibrato. The 11:00 A.M. section was given two forms of the test of energy vibrato and only one form of the test of frequency vibrato. At 2:00 P.M. Form I of the test of frequency vibrato was given to the group. When this test had been given, a bearing in the gear box stuck and the class had to be dismissed without taking the energy vibrato test.

The 9:00 A.M. section was given the tests at the rate of six vibrato pulsations per second. The 11:00 A.M. and 2:00 P.M. sections were given the tests at the rate of seven vibrato pulsations per second.

4. *Results of the extensive series.* The first question investigated was the reliability of the two tests constructed in connection with this study. The reliability of each test was computed in two ways, namely, by repeating duplicate forms and by correlating odd against even columns in the same form, stepping up the resultant coefficient of reliability by means of the Spearman-Brown formula to determine the reliability of the whole test. Due to the fact that a double fatigue order was used in both tests, the sum of the odd columns always presented exactly the same content, in different random orders, as the sum of the even columns. Hence theoretically both these methods should have yielded the same reliability. The coefficients of reliability actually obtained are given in Table III.

It will be noticed that in the case of both tests a higher coefficient of reliability was obtained by correlating odds and evens than by duplicate forms. In order to approximate the true reliability, which probably lies somewhere between the obtained

TABLE III. *Coefficients of reliability for the test of frequency vibrato and test of energy vibrato as obtained from duplicate forms and from odds and evens.*

	Reliability by duplicate forms	Reliability by odds and evens
Test of frequency vibrato	.757	.873
Test of energy vibrato	.813	.850

reliabilities, the average of the obtained reliabilities for each test was found. The resultant coefficients of reliability were:

Test of frequency vibrato, .815
Test of energy vibrato, .830

These reliabilities, while not as high as might be desired, at least compare favorably with the majority of standardized tests. From the results of the tests the distributions of frequency shown in Tables IV, V, VI, and VII were constructed. These distributions of frequency are graphically portrayed in Figs. 5, 6, 7, and 8.

The theoretical consideration that one must be able to perceive differences in pitch before one can perceive a frequency vibrato and the corresponding dependence of an energy vibrato on

TABLE IV. *Distribution of scores of 259 students of elementary psychology on the test of frequency vibrato given at the rate of seven vibrato pulsations per second.*

No. of correct responses	No. of scores in each c.i.	Per cent of scores in each c.i.
195–199	3	1
190–194	26	10
185–189	32	15
180–184	50	19
175–179	50	19
170–174	30	12
165–169	21	8
160–164	13	5
155–159	12	5
150–154	6	2
145–149	8	3
140–144	0	0
135–139	0	0
130–134	1	.5
Total	259	
Mean	177.63	
S.D.	11.40	

TABLE V. *Distribution of scores of* 134 *students of elementary psychology on the test of frequency vibrato given at the rate of six vibrato pulsations per second.*

No. of correct responses	No. of scores in each c.i.	Per cent of scores in each c.i.
195–199	1	1
190–194	4	3
185–189	14	10
180–184	27	20
175–179	26	19
170–174	19	14
165–169	18	13
160–164	11	8
155–159	4	3
150–154	3	2
145–149	2	1.5
140–144	2	1.5
135–139	2	1.5
130–134	1	1
Total	134	
Mean	173.31	
S.D.	11.95	

TABLE VI. *Distribution of scores on* 143 *students of elementary psychology on the test of energy vibrato given at the rate of seven vibrato pulsations per second.*

No. of correct responses	No. of scores in each c.i.	Per cent of scores in each c.i.
226–232	6	4
219–225	12	8
212–218	24	17
205–211	34	24
198–204	26	18
191–197	17	12
184–190	10	7
177–183	6	4
170–176	3	2
163–169	1	1
156–162	1	1
149–155	1	1
142–148	1	1
135–141	0	0
128–134	1	1
Total	143	
Mean	202.91	
S.D.	16.03	

intensity discrimination led to the calculation of a number of intercorrelations. About a month before the administration of the vibrato tests, the same class had been given the Seashore

TABLE VII. *Distribution of scores of* 129 *students of elementary psychology on the test of energy vibrato given at the rate of six vibrato pulsations per second.*

No. of correct responses	No. of scores in each c.i.	Per cent of scores in each c.i.
233–239	23	18
226–232	53	41
219–225	21	16
212–218	11	9
205–211	10	8
198–204	4	3
191–197	2	2
184–190	2	2
177–183	2	2
170–176	1	1
Total	129	
Mean	228.87	
S. D.	10.64	

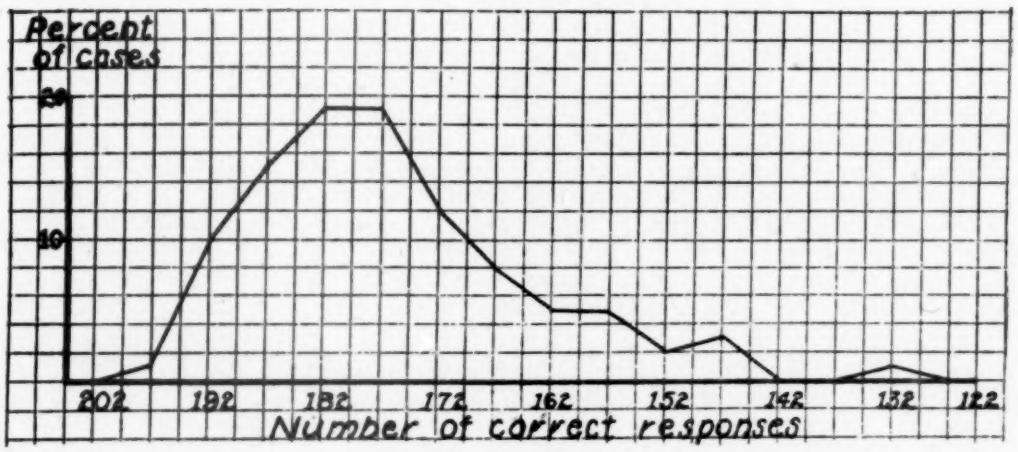

FIG. 5. Frequency polygon showing distribution of scores of 259 students of elementary psychology on test of frequency vibrato given at the rate of seven vibrato pulsations per second

tests of pitch discrimination and intensity discrimination. As many as possible of the latter records were secured and used in the intercorrelations which follow. These correlations are tabulated in Table VIII. The correlations are not all based on the same number of cases for not all of the data were available for every subject. Below each correlation is given the number of cases on which it is based.

The correlations tabulated in this table bring out a number of interesting points. It will be noticed that ability to discriminate pitch, as measured with the Seashore test of pitch dis-

crimination, correlated only very slightly, r = .179, with ability to hear a frequency vibrato occurring at the rate of seven vibrato pulsations per second. Ability to hear a frequency vibrato occurring at the slower rate of six pulsations per second seems

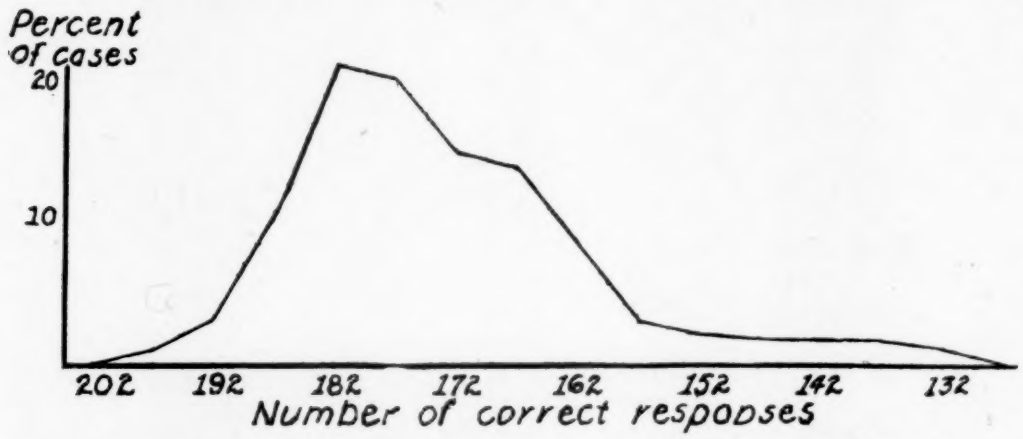

FIG. 6. Frequency polygon showing distribution of scores of 134 students of elementary psychology on test of frequency vibrato given at the rate of six vibrato pulsations per second

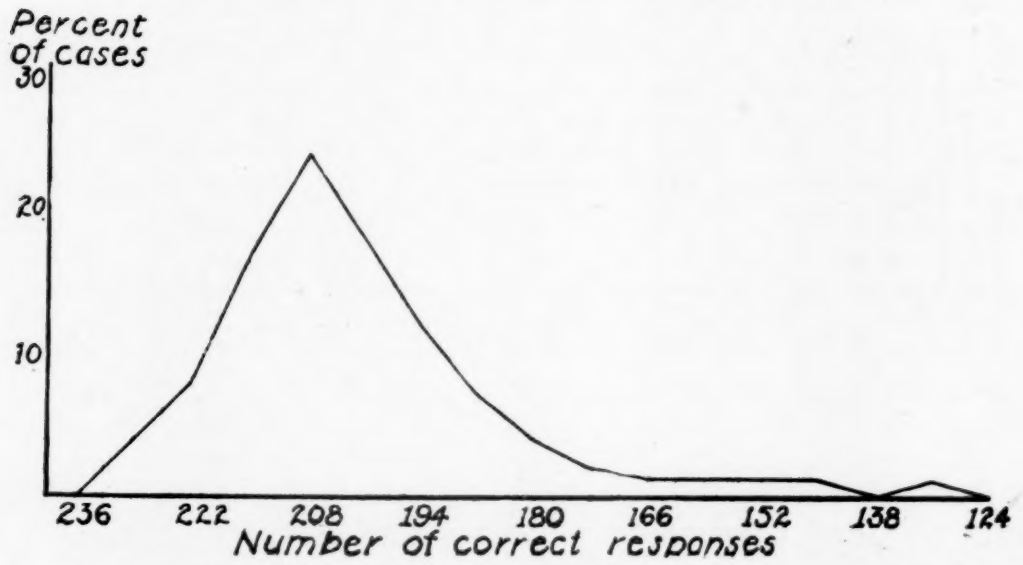

FIG. 7. Frequency polygon showing distribution of scores of 143 students of elementary psychology on test of energy vibrato given at the rate of seven vibrato pulsations per second

to correlate a little higher with pitch discrimination, r = .310. The latter correlation, however, is based on only 50 cases and is probably rather unreliable. It will also be noticed that discrimination of intensity correlates only slightly, r = .118, with ability to hear an energy vibrato occurring at the rate of seven vibrato pulsations per second.

The last column in Table VIII gives the correlations between closeness to the front of the room and the scores obtained on the various group tests. These correlations were calculated and included because the objection has been raised that the score on any group psychophysical test may be influenced by the loudness of the sounds presented. In other words, it has been said that those who sit close to the front of the room are presented with louder tonal stimuli than those near the rear, the resultant scores being influenced accordingly. As can be seen from Table VIII,

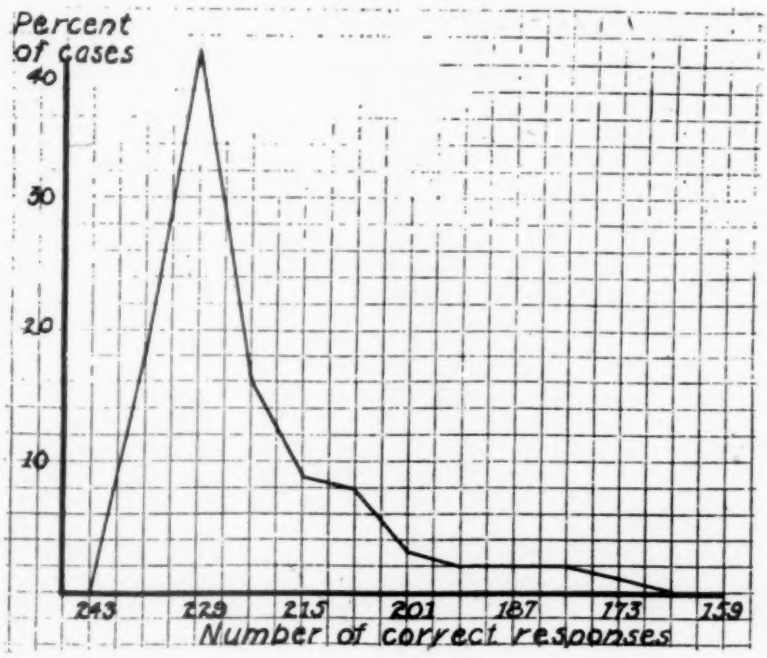

FIG. 8. Frequency polygon showing distribution of scores of 129 students of elementary psychology on test of energy vibrato given at the rate of six vibrato pulsations per second

the correlations between the various tests and closeness to the front of the room, while all positive, are so small as to be negligible.

The only correlation in Table VIII that is significantly large is that between ability to hear a frequency vibrato and ability to hear an energy vibrato. The correlation between these two tests was .677.

One question which can not be directly answered from the raw test scores is the extent in cycles of the minimal perceptible frequency vibrato of the "average" person. The minimal per-

ceptible vibrato is really a psychophysical threshold and it is very difficult if not impossible to secure adequately such thresholds in group experimentation. Since the average threshold, however, was very much desired, an attempt was made to secure some indication of its approximate value from the data available.

It will be remembered that the frequency vibrato test consisted of 200 stimulus tones, distributed so that on each level of frequency extent or difficulty there were 20 vibratos mixed in random order with 20 " straight " tones. Since a subject would

TABLE VIII. *Intercorrelations of group tests*

	Seashore Pitch test	Seashore Intensity test	Frequency vibrato test, 7 pulsations per sec.	Frequency vibrato test, 6 pulsations per sec.	Energy vibrato test, 7 pulsations per sec.	Closeness to front of room
Seashore Pitch test		—.11 N=103	.18 N=101	.31 N=50	.14 N=68	.13 N=149
Seashore Intensity test			.18 N=102	.34 N=56	.12 N=72	.20 N=156
Frequency vibrato test, 7 pulsations per sec.					.68 N=137	.16 N=245
Frequency vibrato test, 6 pulsations per sec.						.04 N=116
Energy vibrato test, 7 pulsations per sec.						.18 N=134

be expected to get half of the forty on each step right by chance and since he would get all forty correct only if he were able perfectly to discriminate between vibratos of that extent and " straight " tones, it was considered that a frequency vibrato which could be distinguished from a " straight " tone in 30 out of the 40 cases, *i.e.*, in 75 per cent of the trials, is the threshold frequency vibrato of the individual in question. Since in only a very few cases did an individual get exactly 30 judgments correct on any one level, the process of linear interpolation[12] was resorted to for the purpose of calculating the thresholds. It

[12] An explanation of the process of computing thresholds by linear interpolation has been given by *Titchener* (24), *Brown* and *Thomson* (4), and others.

will also be remembered that the 9:00 A.M. section of the class in elementary psychology had been given two complete forms of the frequency vibrato test. This made is possible to compute the threshold twice for the individuals in this section, each threshold being computed from a separate set of data. Since the process of computing the thresholds in the above manner involved a considerable labor, 100 subjects were selected at random from the 9:00 A.M. section and the two thresholds for each of these subjects were computed. The reliability of the thresholds computed in this manner was found by correlating the thresholds secured from the data of Form I of the frequency vibrato test against those secured from the data of Form II. When this was done it was found that $r = .618$. For individual measurement this reliability would be entirely inadequate, but for group measurement, which is what we are at present interested in, it is fairly satisfactory. The average threshold computed from the data of Form I of the frequency vibrato test was found to be $.045 \pm .006$ of a step, whereas the average computed from Form II was $.035 \pm .003$ of a step. Since the first presentation of the test involved the factor of unfamiliarity with the procedure, it is probable that the average threshold obtained from the repetition is the more reliable. At a frequency level of 360 ~ one step is equal to 42.28 ~, which would make .035 of a step approximately 1.5 ~. A vibrato approximately 1.5 ~ in extent may thus be accepted as a reasonable approximation to the average threshold frequency vibrato for the 100 individuals tested. Since there is no reason to believe that these 100 individuals do not constitute a random sample as far as vibrato discrimination is concerned, it should also be safe to conclude that the average threshold obtained for them is at least a fairly good indication of the threshold of the average person.

IV. The Intensive Series

1. *Introduction.* All of the work so far mentioned was done upon a large number of subjects. However, a number of the questions raised at the end of section I were still unanswered. In order to secure the additional data necessary to answer these

questions a series of intensive experiments was conducted. Five *O*s were used in each part of the intensive series. All of the *O*s were graduate students in psychology, all were musicians and all had very good pitch discrimination.[13] They were, in fact, chosen primarily on the basis of their records in pitch discrimination, for several of the phenomena investigated required very fine sensitivity to pitch. Also, if five *O*s with very good pitch discrimination experience no change in their vibrato thresholds under various controlled conditions, it is quite safe to assume that the conditions in question will not operate to change the threshold for the average ear, which is less sensitive. Since only five *O*s were used in the intensive series, no attempt was made to treat statistically the results of the group as a whole.

The experiments in this series were all conducted in a soundproof room in the manner described at the end of section II. From two to five *O*s reported at the same time. Since the chairs occupied by the *O*s were approximately equidistant from the source of sound and since the room was deadened to cause a relative absence of reflection, this procedure offered no disadvantage over taking the *O*s singly.

2. *The influence of rate on the threshold of the frequency vibrato.* To answer this question it was necessary to secure a rather exact approximation of the minimal perceptible frequency vibrato for each of the five *O*s at several different rates of vibrato. The constant process, or method of constant stimuli, was used for the determination of the thresholds. The procedure in connection with this study consisted in drilling a disc with the holes so spaced as to produce vibratos of extents .5, 1.0, 1.5, 2.0, and 2.5 ~ with a mean frequency in each case of 420 ~ when the disc was revolved at the rate of seven revolutions per second. A row of holes was also drilled to produce a constant frequency at 420 ~ for purposes of checking. It can be seen that the extents in cycles of the above series form an arithmetic

[13] The *O*s used were Dr. F. O. Smith (Sm), Mr. Lawrence Eberly (Eb), Mr. Scott Reger (Re). Mr. Mack Henderson (He), and Miss Laila Skinner (Sk). Their thresholds for pitch discrimination as computed by the method of right and wrong cases [*Cf. Seashore* (19) and *Fullerton and Cattell* (7)] ranged from .8 to 1.2 ~.

series with a common difference of .5 ~. Equal steps in the stimulus series is a desirable condition in the method of constant stimuli. The *O*s were thoroughly instructed in the nature of a vibrato by presenting them with vibratos of sufficient extent so as to be unmistakable before the experimentation was begun. They were then presented with 50 vibratos on each of the extents indicated above and fifty " straight " tones, the entire 300 stimuli being arranged in random order.[14] The *O*s were instructed to record " + " if they heard a vibrato and " — " if they did not hear one. As was expected, the percentage of positive judgments was very close to zero for all five *O*s when the vibrato presented was very small in extent. As the extent of the vibrato increased the percentage of positive responses became greater until for vibratos 2.5 ~ in extent the observed proportions of positive responses were very close to 1.00. If a graph is laid off with the abscissa representing the extents of the vibratos and the ordinates the observed proportion of positive judgments for each of the vibratos, it can be seen that an empirical ogive will be formed. The procedure of the method of constant stimuli consists in fitting to this empirical curve, by the method of least squares, a curve of the form:

$$y = \frac{1}{\sigma\sqrt{2}} \int_{-\infty}^{(S-T)} e^{\frac{-(S-T)^2}{2\sigma^2}} \, ds$$

The limen or threshold is then defined as the abscissa of the point at which the ordinate of the theoretical curve of best fit has the value .500..... The actual procedure of fitting this curve has been given by *Urban* (25), *Boring* (3), *Titchener* (24), and *Brown and Thomson* (4). *Rich's* checking table was used to insure the accuracy of the computations.[15]

The disc which had been prepared to produce five vibratos

[14] At the beginning of the work 100 tones of each extent were presented. It was soon found, however, that 50 tones of each extent resulted in a degree of reliability quite sufficient for the present work.

[15] The article by *Boring* (3) contains the clearest description of the process of fitting this curve. The tables necessary, *i.e., Urban's* Tables and *Rich's* checking table, are given in the volume by *Brown and Thomson* (4).

whose extents of frequency formed an arithmetic series with a common difference of .5 ~ when revolved seven times per second was also used at other rates of revolution by taking cognizance of the fact that as the speed of the disc is decreased the mean frequency as well as the common difference between extents becomes smaller. Table IX shows the mean frequency and the extents of the five vibratos produced by this disc when operated at different rates of revolution.

TABLE IX. *The extents in ~ of the five vibratos produced by the threshold frequency vibrato disc when revolved at different rates.*

No. of revolutions per sec.	Mean frequency	Extents in ~ of the five vibratos				
5	300	.36	.72	1.07	1.43	1.78
6	360	.43	.86	1.28	1.72	2.14
7	420	.50	1.00	1.50	2.00	2.50
8	480	.57	1.14	1.71	2.28	2.86

We notice from Table IX that as the rate of the vibrato is changed the scale region also changes slightly. It will be shown later that this change is probably not important.

Following the same procedure at each different rate the thresholds were computed for each *O* at five, six, seven, and eight vibrato pulsations per second. A "warming up" period preceded each period of experimentation.

In Table X are tabulated the observed proportions of positive judgments for each *O* for the vibratos of different rates, as well as the limens and the probable errors of the limens (P.E.$_L$) in ~ for each *O* at each different rate.[16]

[16] The probable errors of the limens were computed from the following formula, proposed by *Culler* (4):

$$P.E._L = \frac{.84535}{h\sqrt{2\Sigma nP_P}}$$

Where n = the number of judgments on the step
P = the observed proportion of positive judgments
P = Urban's weight as obtained from the table

$$h = \frac{1}{\sqrt{2\sigma}}$$

From the limens tabulated in Table X the average limen at each of the five rates was calculated. These averages are also given in Table X and are shown graphically by the heavy line in Fig. 9. This figure shows that there is a slight tendency for the limen to become higher as the rate of the vibrato is increased. Since the average, however, increases only about .3 of a vibration between the rates of five and eight vibrato pulsations per second, the increase is probably rather unimportant.

TABLE X. *The observed proportions of tones heard as vibratos at different rates and different extents. Above each column of each section is given the extent of the vibrato in ~*

Rate: 5 vibrato pulsations per second

	Extent of vibrato							
O	0	.36	.72	1.07	1.43	1.78	Limen	P.E.$_{(L)}$
Eb	0	.02	.68	.98	.98	.98	.661	.023
Re	0	.02	.44	.84	1.00	1.00	.774	.035
Sm	0	0	.32	.70	.98	1.00	.872	.034
Sk	.14	.10	.40	.56	.92	.94	.914	.032
He	.22	.24	.76	.92	1.00	1.00	.472	.046
						Mean	.739	

Rate: 6 vibrato pulsations per second

	Extent of vibrato							
O	0	.43	.86	1.28	1.72	2.14	Limen	P.E.$_{(L)}$
Eb	.06	.19	.76	.99	1.00	1.00	.635	.082
Re	0	.04	.52	.90	.99	1.00	.886	.035
Sm	.04	.05	.34	.73	.97	.99	1.013	.049
Sk	.04	.06	.24	.68	.84	.98	1.138	.050
He	.04	.10	.32	.70	.92	.96	1.059	.050
						Mean	.946	

Rate: 7 vibrato pulsations per second

	Extent of vibrato							
O	0	.50	1.00	1.50	2.00	2.50	Limen	P.E.$_{(L)}$
Eb	.02	.03	.53	.81	.99	1.00	.553	.055
Re	0	.02	.53	.85	1.00	1.00	.860	.043
Sm	.07	.09	.34	.61	.91	.97	1.064	.048
Sk	.06	.13	.27	.69	.97	1.00	.750	.090
He	.11	.10	.46	.77	.99	.98	1.155	.052
						Mean	.876	

Rate: 8 vibrato pulsations per second

	Extent of vibrato							
O	0	.57	1.14	1.71	2.28	2.86	Limen	P.E. $_{(L)}$
Eb	.04	.16	.88	.94	1.00	1.00	.859	.053
Re	.02	0	.52	.95	1.00	1.00	1.123	.044
Sm	0	2	.34	.68	1.00	1.00	1.407	.078
Sk	.16	.26	.56	.92	.98	1.00	.901	.071
He	0	.04	.50	.92	1.00	1.00	1.167	.046
					Mean		1.091	

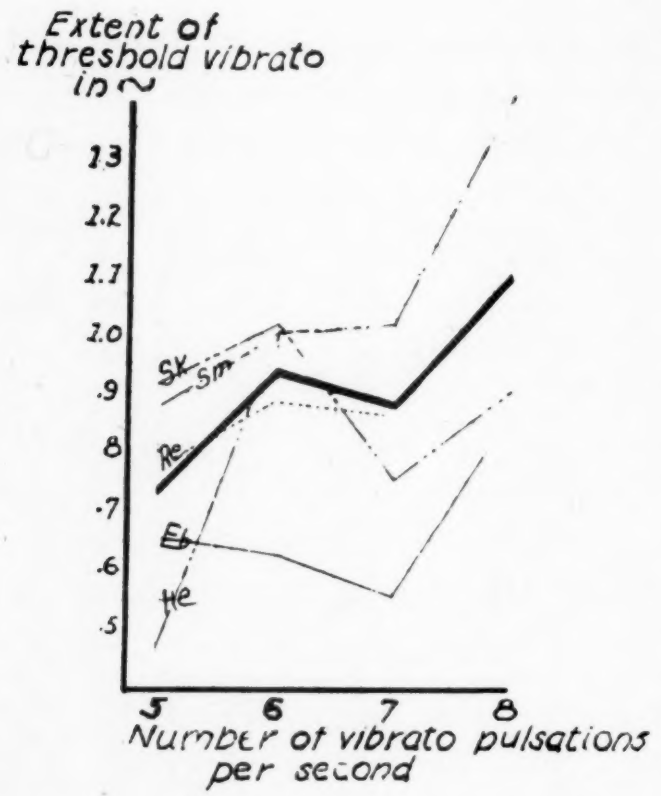

FIG. 9. Curves showing the extent of the threshold frequency vibrato at different rates for five *O*s. The average for the five is indicated by the heavy line.

3. *Effect of scale region on frequency vibrato threshold.* To determine whether the threshold shows marked and consistent differences in different regions of the scale a disc was prepared which would produce five frequency vibratos with extents in cycles forming an arithmetic series and with mean frequencies at 210 ~. In Table XI are tabulated the observed proportions of positive judgments for each *O* for this series of vibratos.

TABLE XI. *The observed proportions of tones heard as vibratos when the mean frequency of the vibratos is at* 210 ~

	Extent of the vibrato							
O	0	.25	.50	.75	1.00	1.25	Limen	P.E. (L)
Eb	0	.02	.02	.56	.96	1.00	.743	.017
Re	.02	.0	.02	.52	.86	1.00	.777	.021
Sm	.04	.06	.10	.56	.92	1.00	.727	.043
Sk	.04	.0	.10	.40	.90	1.00	.774	.024
He	0	0	.02	.56	.92	1.00	.758	.019

The process of obtaining the judgments was exactly the same as described in the preceding section. The limens were again computed by the constant process and are likewise given in Table XI. Fig. 10 shows the change in the limens between the frequencies of 210 and 420. The increase is only about .1 of a ~ and is probably of no significance.

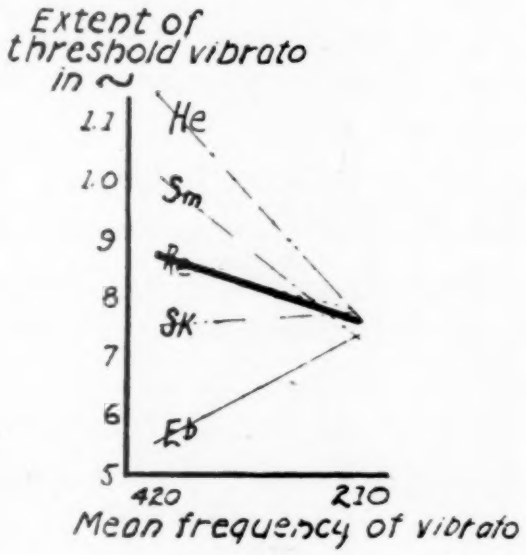

FIG. 10

FIG. 10. Curves showing threshold frequency vibratos for 5 *O*s in two scale regions. Heavy line indicates average.

4. *Effect of a superimposed fluctuation in energy on the threshold of a frequency vibrato.* In this part of the work an attempt was made to find out how the threshold of a frequency vibrato would be affected if an energy vibrato were superimposed upon it in opposite and parallel phase. Following *Kwalwasser* (11) a parallel vibrato is defined as one in which the energy

is greatest when the frequency is highest and an opposite vibrato is one in which the energy is least when the frequency is highest. The procedure of shunting a resistance across the output of the amplifier, as described in the second section, was used to produce the energy vibrato. The disc drilled to produce vibratos of extents 0, .5, 1.0, 1.5, 2.0 and 2.5 ~ at a frequency level of 420 when revolved seven times per second was used. A constant resistance of approximately 2,000 ohms was shunted across the output of the amplifier and the variable resistance producing the energy vibrato was added to this constant resistance. Four series were run, two with parallel vibratos and two with opposite vibratos. The results are graphically portrayed in Fig. 11. Each line represents one *O*, the identity of each *O* being indicated by the key at the bottom. The frequency extents of the vibratos in ~ are given along the base line of each figure and a rough indication of the amount of the superimposed fluctuation in energy, as indicated by the ohmage fluctuation, is given directly below the figures representing the extent. The ordinates represent the observed proportions of positive judgments, or percentage of tones at each level in which a pulsation was heard. Since the curves in which the energy vibrato was not subliminal do not fit the theoretical curve presupposed by the constant process, no attempt was made to compute the theoretical limens from the data. An inspection of the curves, however, indicates that in every case except one (Observer Sk in the diagram for an opposite vibrato 750 ohms) when the energy vibrato itself is not subliminal, the energy vibrato is heard more frequently when by itself than when combined with a frequency vibrato .5 ~ in extent. For example, in the diagram laballed "opposite, 750 ohms," it will be noticed that all the curves except one are higher where the abscissa is zero than where the abscissa is .5 ~. This seems to indicate that some sort of a cancellation effect takes place when an energy vibrato and a frequency vibrato are combined, making the combination less perceptible than either would be alone. It should be mentioned that this phenomenon could be found only with vibratos of very small extent, *i.e.*, of the order

of .5 ~ in extent, and for this reason is probably of no significance musically.

5. *The perceived pitch of a frequency vibrato.* The problem here consisted of an attempt to determine whether or not the

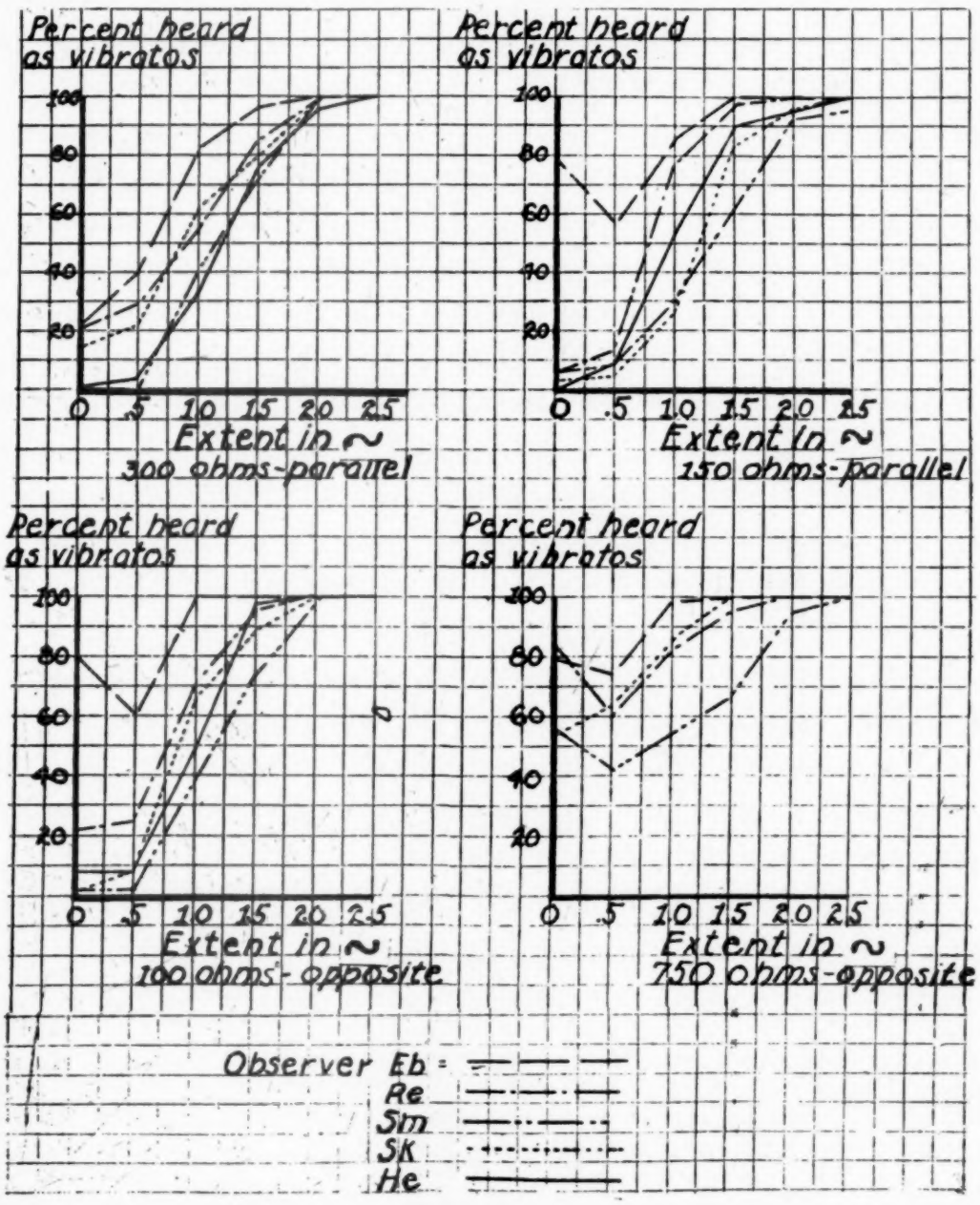

FIG. 11. Curves showing how the threshold frequency vibrato is influenced by a superimposed energy fluctuation.

ear follows the frequency changes in a frequency vibrato, hearing as a result a definite rise and fall of pitch; or whether the ear does not follow the fluctuation in frequency and localizes the tone at a specific pitch. The problem is unique not only in

that there are no experimental data pertinent to it but also in that the very existence of the problem seems to have been overlooked by previous workers in audition.[17]

There are a number of non-experimental works, among which a book by *Stanley* (22) is outstanding, which indicate that probably only a very slight, if any, fluctuation in pitch is *perceived* in a vibrato. *Stanley* states that "The vibrato consists of a periodic swelling and softening of the tone accompanied by a slight rise and fall of pitch. This pitch change, however, is so small as to be practically imperceptible to the ear except, possibly, at very high intensities when the vibrato is extremely broad." As pointed out in the introduction, *Metfessel* (15) has shown that the average vibrato of artists does contain a fluctuation in frequency averaging a half-step in extent. Hence *Stanley's* statement can be true only if the ear will not follow such a rapid oscillation of frequency, successive fusion operating to localize the vibrato tone at a rather definite pitch. The problem can now be restated as an attempt to determine whether such a type of fusion takes place in the vibrato situation.[18]

Several methods of attacking the problem were tried before a satisfactory experimental approach was found. The unsatisfactory attempts will be given in brief because they did bring out certain rather definite results and because they indicate quite clearly the complex nature of the situation in hand.

The first approach to suggest itself was controlled introspection. A number of *O*s with considerable experience in introspection[19] were taken singly and asked to describe vibratos whose

[17] The articles by *Metfessel* (13, 14) are apparently the only exceptions to this statement.

[18] It should be mentioned that, while the specific problem here outlined has received little consideration, there is every presumption from other research in audition against the existence of any such fusion in audition. From such work, for instance, as that of *Bishop* (2), indicating that there is probably no after-image in audition, it might be concluded *a priori* that the ear responds almost instantaneously to changes of frequency and that a fluctuation in frequency occurring only seven times per second would be perfectly perceptible as a fluctuation of pitch.

[19] The *O*s used were Dean C. E. Seashore, Prof. R. H. Wheeler, Prof. Philip G. Clapp, Prof. Stephen Jones, Dr. I. V. Hauge, Dr. H. M. Williams, Dr. Karl Zemen, Mrs. Elinor Easley and Mr. Scott Reger.

constitution was known to *E* but unknown to *O*. The Os were presented with simple frequency vibratos of several extents in frequency, simple energy vibratos, and combinations of the above in both parallel and opposite relation. *O* listened to each tone as long as he desired before attempting a description. The description was then given in terms of pitch, intensity, timbre and duration. It is unnecessary to give a tabulated summary of the introspective reports obtained. None of the *O*s even approached a correct description of the tones, using the physical constitution as the criterion "correct." Frequency vibratos were heard as intensity vibratos; energy vibratos as pitch vibratos; parallels as opposites and opposites as parallels. The most common illusion was to hear a frequency vibrato as an intensity vibrato. The extent of frequency vibratos, when reported as pitch vibratos, was commonly underestimated. Due to the fact that this approach not only failed to reach agreement between *O*s, but also revealed radical inconsistencies in the same *O* it had to be given up.

The next approach consisted in presenting the *O*s[20] with a tone of constant frequency followed by a frequency vibrato and asking them to report according to the following instructions which were read to them:

"In this series of experiments you will hear two tones before each judgment. The first tone will be a non-pulsating tone of very definite pitch; the second tone will be a pulsating tone which *may* or *may not* pulsate in pitch. Listen carefully to the first tone when it is presented, getting its pitch well in mind. When the second or pulsating tone is presented you are to judge whether or not you hear the pitch of the first tone in the pulsating tone. If you hear the pitch of the first or 'straight' tone in the pulsating tone, record +; if not, record —. If the pulsating tone slides in pitch in such a manner that at any time it has the same pitch as the first tone, you are to record +. In other words, if you can hear any exact identity of pitch, even though of short duration. between the two tones, record +. If you hear no identity of pitch in the two tones record —. In the first, or 'straight' tone, there will be a faint periodic noise of no pitch quality in the background. Pay no attention to this noise but concentrate your attention upon the pitch of the tone, which will be very clear and definite. It will contribute to the validity of the experiment and will be greatly appreciated, if you will not discuss the experiment with one another at any time until the series is completed."

[20] The *O*s used in this part of the work were Mr. Scott Reger (Re), Mr. Lawrence Eberly (Eb), Miss Laila Skinner (Sk), Mr. Mack Henderson (He), and Miss Katherine Robinson (Ro).

The mean frequency of the vibrato in each case was 420 ~ and the " straight " tones which preceded the vibrato were of frequencies 408, 412, 416, 420, 424, 428, and 432 ~. Each of the " straight " tones was compared with the vibrato 50 times, making 350 judgments in all, presented in random order. The entire procedure was repeated with four different vibratos, one .5 of a step in extent, one .3 of a step, one .1 of a step and one a simple energy vibrato with no fluctuation in frequency at all.

It was expected that if a fluctuation in pitch is perceived in a frequency vibrato that the judgments would be + as long as the " straight " tone was encompassed by the fluctuation in frequency and that when the " straight " tone was outside the limits of the fluctuation in frequency the judgments would be —. Fig. 12 graphically represents what actually happened with four *O*s. The fifth *O* was not available for all of the work. Each of the small diagrams represents one *O* and each line represents a vibrato of different frequency extent. The legend at the bottom shows the extent in frequency in cycles of the vibrato represented by each type of line. The ordinates represent the per cent of positive judgments and the abscissa the frequency of the " straight " tones which were compared with the vibrato.

It will be noticed that there is no significant narrowing of the curve as the extent in frequency of the vibrato is decreased and that the heavy black line, representing the energy vibrato is, on the average, fully as high as the narrow black line, which represents a vibrato .5 of a step in extent.

Due to the fact that even in the case of the simple energy vibrato, tones whose frequencies were as far as eight vibrations from the limits of the vibrato frequencies were reported as " heard " in the pulsating tone a large percentage of times by all of the *O*s, it seemed that the instructions were operating in such a way as to cause the listener to report things obviously not sensed. Hence this approach was abandoned, its single positive result being a fairly conclusive demonstration of the fact that with this *Aufgabe* the *O*s used could not distinguish a frequency vibrato .5 of a step or less in extent from an energy vibrato.

The next attack made differed from the preceding one primarily in the instructions, the method of judging, and the treatment of the observed proportions of positive judgments secured. The *O*s were requested to judge whether the pitch of a tone of

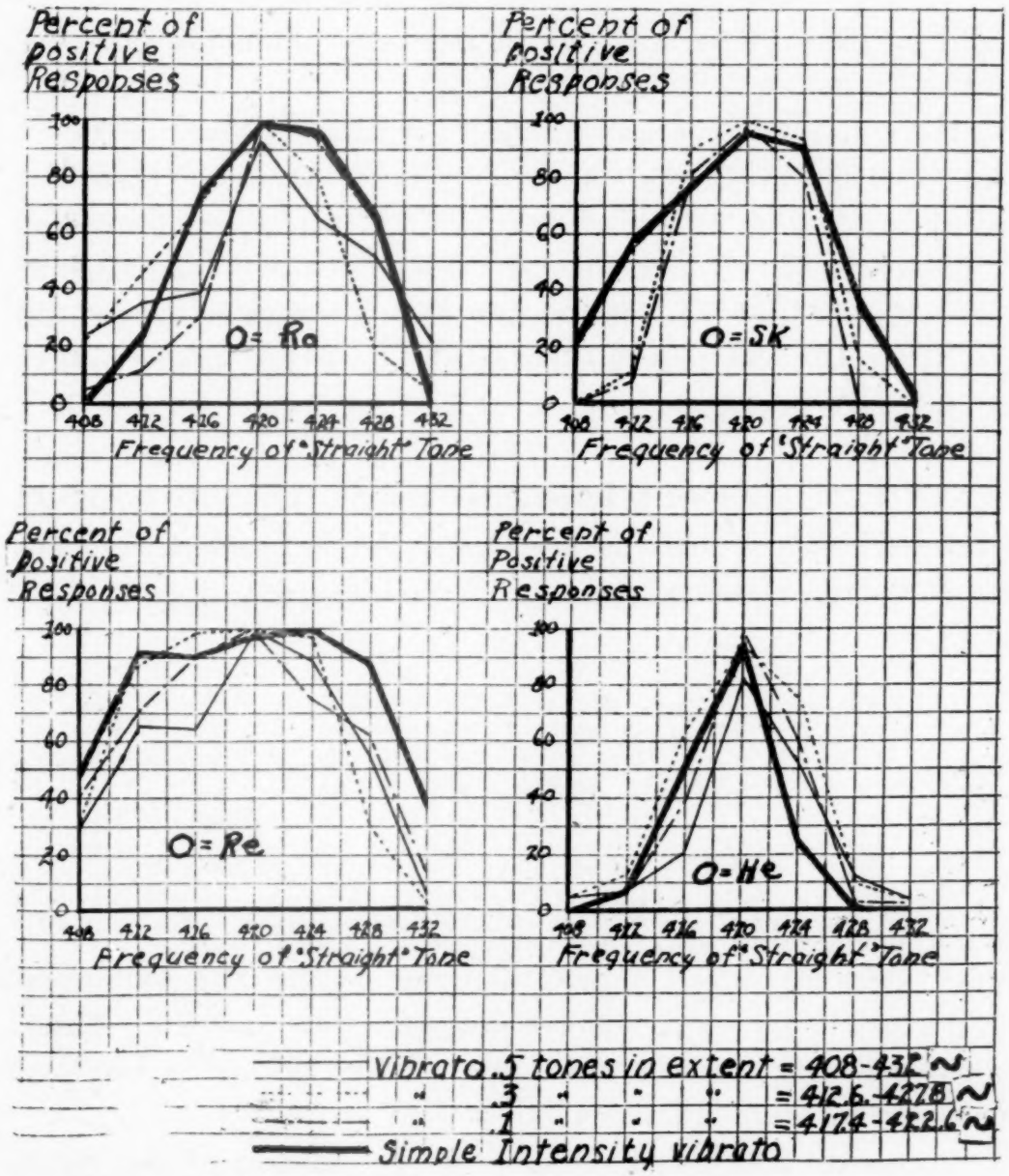
Percent of positive Responses
O = Ra
O = SK
O = Re
O = He
Frequency of "Straight" Tone
Vibrato .5 tones in extent = 408-432 ~
" .3 " " " = 412.6-427.8 ~
" .1 " " " = 417.4-422.6 ~
Simple Intensity vibrato

FIG. 12. Curves showing the attempts of four *O*s to identify the frequencies encompassed by frequency vibrates of different extents.

constant frequency is higher or lower than the pitch of a vibrato tone. In the first series under this plan "straight" tones of frequencies 408, 412, 416, 420, 424, 428, and 432 were compared with a vibrato .3 of a step in extent (the extent in fre-

quency of the vibrato was 412.3 to 427.8 ~.) The *O*s were forced to render a judgment of higher or lower on the assumption that if the frequency vibrato is perceived as a fluctuation of pitch, the resulting " wobbly " pitch goes above and below the pitch of the " straight " tone and the judgments are thereby reduced to mere guesses, in which case approximately one-half would be higher and one-half lower.

Each " straight " tone was compared with the vibrato 50 times 25 times with the vibrato followed by the " straight " tone and 25 times in reversed order. The entire 350 pairs were presented in random order. The results of this series are tabulated in Table XII, the figures representing the per cent of times, or observed proportions, that the " straight " tone was judged higher in pitch than the vibrato.

TABLE XII. *Observed proportions that " straight " tones of frequencies indicated were judged higher than a frequency vibrato extending from* 412.6 *to* 427.8 ~

	Frequency of " straight " tone						
O	408	412	416	420	424	428	432
Re	0	.04	.22	.80	.96	1.00	1.00
Eb	0	0	0	.52	.98	1.00	1.00
Re	0	.02	.12	.42	.72	.94	.98
Sk	0	0	.02	.60	.98	1.00	1.00
He	0	0	.10	.84	1.00	1.00	1.00

From Table XII it is obvious that the frequencies 408 and 412 are very seldom judged higher than the vibrato and that those of 428 and 432 are nearly always judged higher than the vibrato. Accordingly it seems that the pitch of the vibrato is localized somewhere between 416 and 424 ~.

To secure an adequate indication of the location of this pitch, as well as a measure of the definiteness of the localization, we were compelled to use comparison pitches whose frequencies were closer to the mean frequency of the vibrato and separated from each other by intervals smaller than 4 ~. For this purpose a new set of discs was constructed which would permit a comparison of the vibrato with frequencies ranging from 416 to

424 ~ in steps separated by 1.3 ~. The same procedure outlined above was followed with the new comparison stimuli. The observed proportions that the " straight "tone was judged higher in pitch than the vibrato tone by the five *O*s for vibratos .1, .3, .5, .75, and 1.0 steps in extent are given in Table XIII.

In Table XIII it will be noticed that the observed proportions across any line increase in a manner which strikingly suggests the manner of increment found in data to which the phi-gamma function is applicable. We immediately recognized that if this function could be used with our data it would furnish a very adequate means of determining the pitch at which a frequency vibrato is localized as well as a reliable measure of the definiteness of the localization in the form of the standard deviation of the integral form of the normal probability curve of best fit. Accordingly, this method was employed and a number of sets of data fitted to the psychophysical function. The chi-square test of goodness of fit was employed and indicated that there is very good justification for using this curve for the data in hand.

TABLE XIII. *Observed proportions that " straight " tones of frequencies indicated were judged higher in pitch than frequency vibratos of different extents*

For vibrato .1 of a step in extent

Frequency of " straight " tone

O	416	417.3	418.6	420	421.3	422.6	424	Mean	s.d.
Eb	.02	0	.14	.38	.62	.80	.96	420.7	2.0
Re	.04	.32	.56	.62	.78	.96	1.00	418.8	2.4
Sk	.02	0	.22	.58	.68	.96	1.00	419.9	1.8
He	0	.04	.18	.56	.86	.98	1.00	419.8	1.3
Ro	.10	.14	.26	.58	.76	.92	.98	419.6	2.3

For vibrato .3 of a step in extent

Frequency of " straight " tone

O	416	417.3	418.6	420	421.3	422.6	424	Mean	s.d.
Eb	.02	.02	.20	.36	.44	.88	.98	420.8	2.2
Re	.14	.18	.78	.80	.88	.94	.98	418.3	2.3
Sk	.14	.18	.62	.70	.90	.94	1.00	418.5	2.4
He	.06	.06	.28	.50	.78	.94	.98	419.8	2.0
Ro	.22	.20	.48	.60	.64	.62	.78	419.5	3.7

For vibrato .5 of a step in extent

Frequency of "straight" tone

O	416	417.3	418.6	420	421.3	422.6	424	Mean	s.d.
Eb	.16	.32	.46	.50	.68	.72	.96	419.5	3.8
Re	.16	.32	.68	.84	.90	.96	.98	418.1	2.4
Sk	.10	.36	.82	.98	1.00	1.00	.98	417.6	1.2
He	.12	.16	.44	.66	.80	.96	1.00	419.2	2.0
Ro	.08	.22	.30	.60	.54	.80	.98	420.0	2.9

For vibrato .75 of a step in extent

Frequency of "straight" tone

O	416	417.3	418.6	420	421.3	422.6	424	Mean	s.d.
Eb	.10	.32	.44	.52	.50	.66	.82	420.3	4.6
Re	.40	.54	.96	.98	1.00	.98	1.00	416.7	1.3
Sk	.06	.18	.20	.52	.56	.80	.84	420.5	3.0
He	.14	.18	.44	.56	.64	.88	.94	419.6	3.0
Ro	.20	.44	.62	.72	.86	.94	.96	418.1	3.0

For vibrato 1.00 step in extent

Frequency of "straight" tone

O	416	417.3	418.6	420	421.3	422.6	424	Mean	s.d.
Eb	.26	.42	.61	.77	.78	.89	.97	417.9	3.6
Re	.44	.87	.97	.99	1.00	1.00	1.00	416.1	1.4
Sk	0	0	.01	.04	0	.04	.07	428.8	4.7
He	.36	.43	.61	.88	.84	.94	.97	417.4	3.3
Ro	.73	.76	.87	1.00	.99	1.00	1.00	413.1	5.2

The remainder of the sets of data were then fitted to the phi-gamma curve. The perceived pitch of the vibrato is then defined, after the manner of psychophysical work, as the abcissa of the point at which the theoretical curve of best fit has an ordinate equal to .500·····. The definiteness with which this pitch is localized is quantitatively expressed by $h = \frac{1}{\sigma\sqrt{2}}$. Because of the more universal use of the standard deviation as a measure of variability, the s.d. of each of the fitted curves was obtained from the above relation. In Table XIII the pitch at which the frequency vibrato was localized by each *O* is given in next to the last column, and the definiteness of this localization, measured by the s.d. of the curve of best fit, is given in the last column.

Fig. 13 graphically shows the perceived pitch of vibratos of different extents. Each line represents a different *O*, their identity being indicated. The abcissa gives the extent of the

vibrato in cycles and the ordinate the perceived pitch. The mean frequency of each vibrato was 420 ~. Fig. 13 shows that all of the *O*s localized the pitch quite near the mean frequency until the extent of the vibrato was increased to between 30 and 40 ~, which at this point in the scale is equivalent to between .75 and 1.00 steps. When the extent of the vibrato was increased to 1.00 step, four of the *O*s showed a decided drop in the pitch of the localized tone and one a considerable rise. It will also be noticed that before this point is reached there seems to be fairly

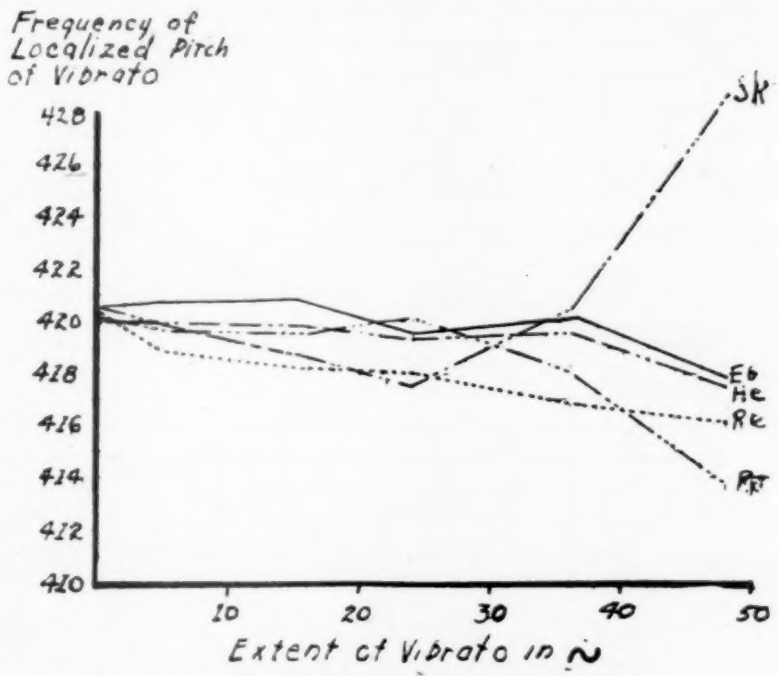

FIG. 13. Curves showing the perceived pitch of frequency vibratos of different extent, all with a mean physical frequency of 420 ~.

uniform tendency to flatting in the localization of the vibrato tone, the amount of the flatting being roughly proportional to the extent of the vibrato.

The data of most significance are given in the last column of Table XIII and are shown graphically in Fig. 14. These figures give the value of the standard deviation of the phi-gamma curve of best fit for different *O*s and vibratos of different extents. In Fig. 14 the extent of the vibrato, both in cycles and in fractions of a step, is given on the abcissa and the value of the s.d., which is a measure of the definiteness with which the pitch of the vibrato is localized, is given on the ordi-

nate. The five light lines represent the five *O*s, their identity being indicated on the graph. The heavy line represents the average for the five. It can be seen from Fig. 14 that a vibrato .1 of a step or 5.2 ~, in extent, is localized practically as definitely as a vibrato of zero extent, *i.e.*, a " straight " tone. When the extent of the vibrato is increased from 5.2 ~ to 26.2 ~, *i.e.*, an increase of about 700%, it can be seen that the pitch localization becomes on the average only about 30% more indefinite.

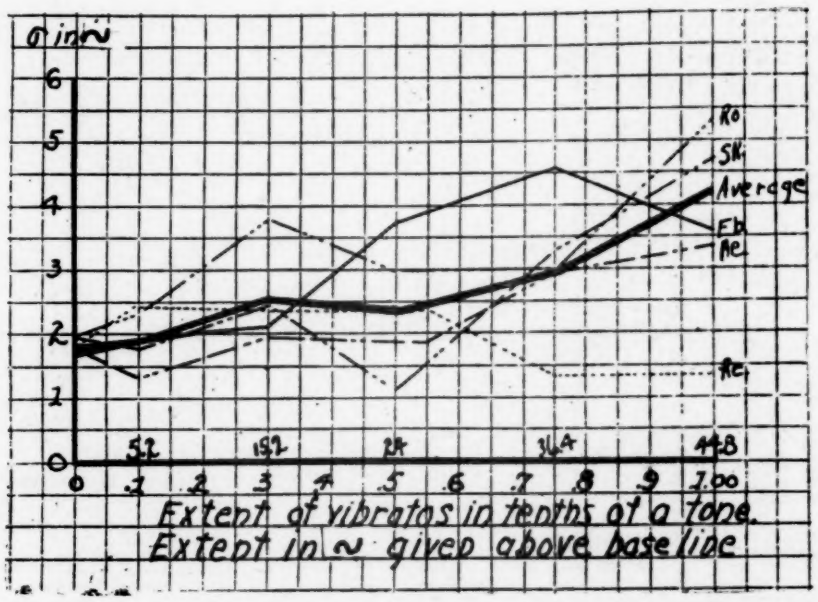

FIG. 14. Curves showing the definiteness of the perceived pitch of frequency vibratos of different extents.

We notice that in Fig. 14 the curve shows the definiteness with which a vibrato of zero extent, *i.e.*, a " straight " tone of frequency 420 ~ is localized. The value of the s.d. for this hypothetical vibrato was secured in the same manner as that used with the real frequency vibratos and was obtained merely for the purpose of determining how definitely a constant frequency is localized with the tone generating apparatus being used. Table XIV gives the observed proportions with which the respective comparison tones were judged higher in pitch than the " straight " tone at 420 ~.

An inspection of the heavy line in Fig. 14 shows that the

localization of the pitch of a vibrato .5 of a step or less in extent is only slightly less definite for the five *O*s used than is the localization for a " straight " tone of 420 ~.

TABLE XIV. *Observed proportions that the respective " straight " tones were judged higher than a " straight " tone at* 420 ~

	Frequency of comparison tones								
O	416	417.3	418.6	420	421.3	422.6	424	Mean	s.d.
Eb	0	0	.04	.48	.52	.98	1.00	420.5	1.6
Re	0	.02	.20	.52	.70	.90	.98	420.2	1.8
Sk	0	0	.12	.50	.60	1.00	1.00	420.5	1.9
He	0	0	.22	.60	.76	1.00	.96	419.9	1.8
Ro	.10	.04	.18	.52	.80	.90	.94	420.2	1.9

6. *The effect of a superimposed fluctuation of energy on the pitch heard in a frequency vibrato.* In order to secure a qualitative statement of the manner in which a vibrato with a superimposed energy affects the pitch of a frequency vibrato the following short series was run. The pitch of a parallel vibrato, .5 of a step in extent with a mean frequency of 420 and occurring at seven vibrato pulsations per second, was compared 50 times each with seven " straight " tones ranging in frequency from 416 to 424 ~. In one-half of the judgments the vibrato was followed by the " straight " tone and in one-half of the judgments the reversed procedure was followed. The pitch of the vibrato was compared with that of the " straight " tone. Only higher and lower judgments were allowed. The pitch of the vibrato tone was calculated by fitting an integral form of the normal probability curve, the phi-gamma function referred to above, to the seven observed proportions, each observed proportion being the proportion of the number of times that the pitch of the " straight " tone was judged higher than that of the vibrato. The pitch of the vibrato is defined as the abcissa of the point on the theoretical curve which has an ordinate equal to .500·····. In the same manner the pitch of an opposite vibrato was calculated from analogous data. In Table XV are given the observed proportions for the parallel and opposite

vibratos. Fig. 15 graphically shows the way in which the pitch of the vibrato tone changed due to the addition of a parallel or opposite fluctuation in energy. Since the absolute amount of the fluctuation in energy could not be measured, but was adjusted subjectively so as to be about as perceptible as a half-step frequency vibrato, this data can only be considered as a rough indication of the manner in which a fluctuation in energy influences the pitch of the tone.

TABLE XV. *Observed proportions that "straight" tones of frequencies indicated were judged higher than a parallel and opposite vibrato*

Parallel frequency energy vibrato

	Frequency of "straight" tone								
O	416	417.3	418.6	420	421.3	422.6	424	Mean	s.d.
Eb	0	.04	.18	.28	.18	.50	.92	422.0	2.8
Re	.06	.28	.48	.44	.50	.70	.88	420.3	3.9
Sk	0	0	.02	.18	.36	.88	.94	421.5	1.4
He	0	.02	.06	.20	.38	.72	.90	421.6	1.9
Ro	.04	.04	.20	.26	.44	.60	.90	421.7	3.5

Opposite frequency energy vibrato

	Frequency of "straight" tone								
O	416	417.3	418.6	420	421.3	422.6	424	Mean	s.d.
Eb	.20	.36	.76	.92	.84	1.00	.98	417.8	2.4
Re	.46	.54	.86	.96	.98	1.00	1.00	416.5	2.1
Sk	.02	.12	.72	.98	.98	1.00	1.00	418.2	1.1
He	.06	.14	.80	.90	.98	.98	1.00	418.2	1.5
Ro	.12	.40	.78	.98	.94	.98	1.00	417.7	1.9

From Fig. 15 it can be seen that the pitch of the parallel vibrato is localized on the average about 2.0 ~ higher than the mean physical frequency and the pitch of the opposite vibrato about 2.0 ~ lower than the mean physical frequency.

V. SUMMARY AND CONCLUSIONS

In this study an attempt was made to apply the traditional psychophysical approach to the vibrato. An apparatus was developed for producing the vibrato synthetically with the rate, extent of the frequency fluctuation, amount of the fluctuation in energy and the phase relationship frequency-energy under

separate control.[21] Tests of ability to hear a frequency vibrato and ability to hear an energy vibrato were constructed

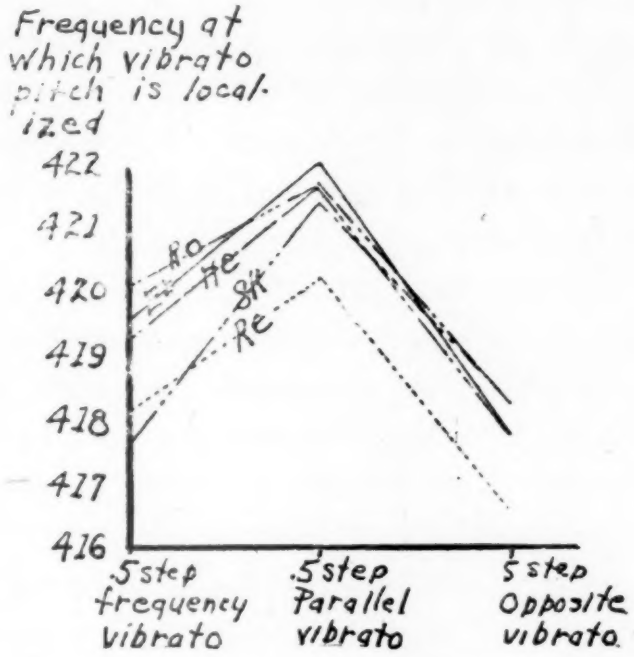

FIG. 15. Curves showing how the pitch of a frequency vibrato is changed by a superimposed energy vibrato.

[21] The purpose of the apparatus was to produce a vibrato identical as nearly as possible in its characteristics with the vibrato actually employed by artistic singers. It was of course impossible exactly to duplicate the performance of artistic singers, mainly because of the fact that the wave-form or timbre of the voice could not be duplicated with the siren apparatus. Hence any conclusions based on the results of this study must be limited to the extent that the phenomena observed behave differently with different wave-forms. The fact, however, that the phenomena apparently operate quite uniformly not only with different singers, who must of course have different wave-forms, but also with different musical instruments which utilize a vibrato, leads us to assume that frequency and energy are probably the primary factors which determine how a vibrato is heard. These factors are under quite adequate control with the apparatus used.

In interpreting the results of this work it should also be remembered that a vibrato has been used throughout whose frequency is a *sine function of time*. A vocal vibrato does not rigidly adhere in form to any mathematical function. Sometimes the high frequency part of the pulsation is of slightly longer duration than the low frequency and sometimes the reverse conditions obtain. As pointed out in the beginning, however, it seems quite safe to assume that a sine vibrato is as representative a form as can be conveniently found in a simple mathematical function. It should be kept in mind that to the extent that the form of the vibrato is significant psychophysically and differs from a sine curve, the conclusions of this study must be considered only as approximations to those which would result if the artist's form were exactly duplicated.

and given to 394 students of elementary psychology. The process of linear interpolation was resorted to for the purpose of securing the approximate value of the threshold frequency vibrato of the "average" person. In addition, an intensive investigation was made with five *O*s to determine certain systematic tendencies in the hearing of the vibrato. The constant process or method of constant stimuli was used exclusively in this intensive series.

The results of the group investigation indicate that:

1. There are large individual differences in the ability to hear a frequency vibrato. A test constructed for measuring this ability showed an A.M. of 177.6 and a s.d. of 11.4, with a reliability coefficient of .82. Results are given from which tentative norms may be deduced.

2. There are large individual differences in the ability to hear an energy vibrato. A test constructed for measuring this ability showed an A.M. of 202.9 and a s.d. of 16.03, with a reliability coefficient of .83. Results are given from which tentative norms for this ability may be deduced.

3. There is a fairly high correlation, r =.68, between ability to hear a frequency vibrato and ability to hear an energy vibrato.

4. There does not seem to be a significant relationship between pitch discrimination and ability to hear a frequency vibrato occurring at a rate of seven vibrato pulsations per second.

5. There does not seem to be a significant relationship between ability to hear an energy vibrato occurring at the rate of seven pulsations per second and discrimination of intensity.

6. The threshold frequency vibrato for the average person is probably quite close to 1.5 ~ in extent when the mean frequency of the vibrato is near 420 ~. This statement is based on the average threshold for 100 random members of the class in elementary psychology.

7. Distance from the source of sound is of neglibible importance in the frequency vibrato test, the energy vibrato test, the

Seashore test of discrimination of pitch and the Seashore test of discrimination of intensity.

The results of the intensive series indicate that:

1. The threshold frequency vibrato is not significantly influenced by the rate of the vibrato between the rates of five and eight vibrato pulsations per second.

2. The threshold frequency vibrato has approximately the same extent in ~ in the scale region around 210 ~ and around 420 ~.

3. A vibrato with a superimposed energy may tend to cancel a very small frequency vibrato, but the effect is probably so slight as to be of no importance in music.

4. It is extremely difficult, if not impossible, to distinguish between a frequency vibrato and an energy vibrato on the basis of fluctuations of pitch.[22] It is possible that the two types of vibrato may be distinguishable on the basis of the distinctive quality of each due to its specific type of sonance.

5. The pitch of the frequency vibrato is localized slightly below the mean frequency, the amount of the flatting being roughly proportional to the extent of the vibrato. When the extent of the vibrato is increased to between .75 and 1.00 step, the pitch is localized very far from the mean frequency, sometimes higher and sometimes lower.

6. The pitch of a vibrato up to a half-step in extent is localized practically as definitely as the pitch of a tone of constant frequency. As the extent of the vibrato is increased beyond a half-step the localization becomes less definite.

7. The perceived pitch of a frequency vibrato is raised by the addition of a parallel fluctuation in energy and lowered by the addition of an opposite fluctuation in energy.

[22] The work here reported does not definitely determine whether fluctuations of pitch can be heard in a frequency vibrato. All that it shows is that frequency and energy vibratos are very often confused and that the pitch of a frequency vibrato is localized very definitely near the mean frequency and slightly flat. One of the major problems for future investigation in this field is to determine how accurately the ear does follow the fluctuations of frequency and energy in the vibrato and the conditions which lead to the confusion of pitch and intensity in the situation of the vibrato.

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THE RELATION BETWEEN THE PHYSICAL PATTERN AND THE REPRODUCTION OF SHORT TEMPORAL INTERVALS: A STUDY IN THE PERCEPTION OF FILLED AND UNFILLED TIME[1]

by

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I. STATEMENT OF THE PROBLEM

It is well known that the perception of visual extent depends in part upon the nature of the physical form by means of which the extent is presented. For example, a straight line which has been cross-hatched will appear longer than one of equal extent which has been left plain and a line will appear longer than an unfilled space between two dots (12, 192; 44, 157). The estimation of time is likewise related to the type of experience which is going on during the interval which we wish to estimate. Everyone is familiar with the fact that a full hour goes more quickly than an empty one. The selfsame hour may speed by in a flash for the lecturer who has a quantity of material which he is eager to deliver, or it may appear interminable to the bored listener who can not grasp the lecturer's ideas and for whom, therefore, the hour is relatively empty. The illusion due to the filling of short times is not so obvious, however, nor has it been so definitely determined as in the case of the filling of short visual extents. There is a difference between long and short times in that in the latter the "filling" does not consist of ideational material but of simple sensory material. The interest is in the relation between the physical pattern of stimulation and the apparent length of the interval. This is the field of inquiry of the present study.

[1] This study was carried out under the direction of Dr. Christian A. Ruckmick.

The specific problem of this investigation originated in the observation that in the Seashore test for time discrimination (**38**, 103 f.; **39**) the intervals to be judged are empty durations bounded by short clicks, whereas in the actual situation of musical performance accuracy of perception of filled tonal intervals is called for, as well as accuracy of perception of empty intervals, or rests. The further observation arose that there might be a difference in the estimation of temporal intervals, not only according to whether or not the intervals were filled, but also according to the pitch of the tones with which they were filled, or, in the case of rests, according to the pitch of the tones by which they were surrounded. Finally, in the musical situation temporal estimation takes the form of a motor response, for the musician must make a movement of vocal organs or of fingers or feet in order to sing or play each note and he must make this movement last a given time in order that the tone may fit in properly with the rhythm of the musical passage.

The central problem of the study, then, is the comparison of the reproduction of temporal intervals when the standard and reproduced intervals are filled with tones and when they are empty so far as sensory content is concerned. In order to secure as sharp a contrast as possible between the two situations the "unfilled" intervals were presented, not as silent intervals bounded by clicks, as has been customary in studies of temporal perception, but as silences in a background of constant tone. These were the principal unfilled intervals. Empty intervals bounded by clicks were used in control series. A secondary problem was in reference to the effect of the pitch of the tonal filling or background upon the estimation of the two principal types of interval. The pitches used corresponded to the frequencies 128, 256, 512, and 1024 ~, and the durations centered about 0.5, 1.5, and 2.5 sec.

In view of the consideration, mentioned above, that in musical performance temporal estimation is a motor response, the method of reproduction was chosen for experimentation.

II. Historical Summary of Experimental Work

In experimental work on the perception of short temporal intervals there have been five principal objectives. These may be designated as follows: the investigation of the applicability of Weber's law, the location of the indifference zone, the discovery of secondary criteria for the estimation of time, the investigation of the relation between the physical pattern and the estimation of time, and the investigation of temporal perception in relation to music. References to representative studies in each of these fields will be found in the bibliography which follows this article and a summary of these studies is included in the full report of the present experiment. The comparison of filled and unfilled short temporal intervals falls within the fourth of the fields named above, *i.e.,* the investigation of the relation between the physical pattern and the estimation of time. A survey of studies on this problem will follow.

The comparison of filled and unfilled short temporal intervals. Meumann was the first investigator to formulate in detail the problem of the difference between the perception of filled and unfilled short temporal intervals, but his work was actually preceded by a number of other studies in which filled intervals were used. *Meumann* himself gives the fullest available report of the work of *Thorkelson,* which has been published only in the original Danish.[2] The use of filled intervals seems, however, to have been an incidental detail with *Thorkelson,* as he makes no comparison with unfilled intervals, so far as *Meumann* reports (21, 432–440). *Meumann* belives that the idea of filling intervals is a good one in itself because it avoids the subjective filling of the intervals and disturbances from the outer senses (21, 440).

One section of a study published by *Hall* and *Jastrow* in 1886 was devoted to a comparison of full and vacant intervals (11). To the two *O*s were presented two intervals, the first filled with clicks, the second vacant. The conclusions follow:

> "With ten clicks the following vacant interval to be judged equal to it must be extended to the time of 14 to 18 clicks; 15 clicks seemed equal to

[2] Thorkelson. *Undersögelse af Tidssansen.* Christiania, 1885.

the time of from 16 to 19. Preliminary experiments upon other individuals indicate that these differences are extreme. If the absolute length of the interval is increased beyond from one to three seconds, the illusion is less. It is also less if the clicks are very near together. . . . This entire illusion, however, is reduced to a minimum and with some persons vanishes, if the order of the terms be reversed, *viz.*, if the vacant or less filled interval precedes" (**26**, 526–527; 11, 62).

The authors draw an analogy between this illusion and the illusion of visual extent which occurs when a line is bisected and one half is criss-crossed, whereas the other half is left plain. If the temporal illusion, however, depends upon the order of the interrupted and empty intervals it is difficult to believe that a true analogy exists.

A study by *Ejner* in 1889, reported by *Kraepelin,* under whose direction it was performed, does not strictly belong in this group because the intervals used were from 30 to 240 sec., but is of interest because of its early date. When *O* gave 25 reproductions of the standard time of 30 sec., the average of these was longer than the standard, whether the intervals had been filled with metronome beats or whether they had been vacant. The error was less, however, with the filling than without it (**17**, 32, 146). With a single reproduction, however, the error was negative—*i.e.,* the reproduction was shorter than the standard (**26**, 519).

Münsterberg's experiments with filled intervals, published in 1892, used different fillings in the standard and compared intervals. His conclusion was that the filling made little difference, so long as it did not entirely engross *O*'s attention, thus drawing it away from the muscular sensations, which he believed to be the essential criteria for temporal judgment (**25**, 117).

Münsterberg's repudiation in 1889 of the concept of the "time sense" implies that all experienced time is filled time. For him the significant filling was muscular sensation (**31**; **26**). *Meumann* disagreed with *Münsterberg* on this latter point, but he likewise emphasized the idea that when we speak of "filled intervals" we are merely using relative terms, for the so-called "empty intervals" have likewise a conscious content, though of a different nature. He contrasts the two types of intervals as follows:

> While in the case of artificially filled intervals "the sensory content dominates strongly in consciousness, in the case of 'empty' times this does not happen. Their sensory content is always diffused and undefined. It is, moreover, of minimal intensity in comparison with any artificially introduced sound or light impressions. . . . Most (artificial) fillings bring about a more or less strong quality or intensity change of the (conscious) content. Further, in the case of stimulus-bounded (empty) times the beginning and end moments of the time interval are strongly marked and are as instantaneous as possible, the times stand out sharply limited before the inner perception. In contrast filled times through their filling always lose in definiteness of their beginning and ending moments" (**23**, 137–138).

It may be noted here that in respect to the last point in the above quotation from *Meumann* the unfilled intervals used in the present study resemble the filled intervals more than they resemble the click or stimulus-bounded intervals.

The purpose of *Meumann's* experiments, published in 1896, was to find for what absolute temporal values filling has a marked influence, and how different fillings affect the judgment at these values (**23**, 135). He used a method of judgment rather than one of reproduction—*i.e.*, the method of gradations with irregularly changing differences. There was always an intermediate time between the two intervals to be compared and these two intervals were always of a different nature—*i.e.*, one filled and one unfilled. The order of the filled and unfilled intervals was varied in different experimental series and a number of different fillings were used, varying from three clicks to a continuous smooth tone. The standard intervals varied from 0.2 to 10.0 sec. With the discontinuous fillings the filled time was overestimated [3] in the shorter times and underestimated in the longer times, regardless of order of filled and unfilled intervals, except that this order affected the location of the indifference zone (**23**, 163–177). With the continuous filling the filled interval was overestimated for all durations from 0.3 to 10.0 sec. when it was given first, but when it was in the second position it was underestimated for the very small durations, overestimated for longer durations, and again underestimated for still longer durations (**23**, 212–214). In general he finds the illusion with the

[3] In reporting results the term "overestimation" will be applied to the second interval when the constant error is negative and "underestimation" of the second interval will be spoken of when the constant error is positive.

continuous filling similar to, but less than with the discontinuous filling (**23**, 224, 249). *Meumann's* explanation rests chiefly upon the energy with which attention is drawn to the various intervals. This depends upon duration, physical pattern, and position of the interval. That interval which on account of any given combination of these factors has the greater importance (*Gewicht*) in consciousness is judged the longer (**23**, 168).

In a study by *Gilbert,* published in 1894, children six to seventeen years of age were subjects. The filling sound was produced by the chronoscope, which made a loud tone, presumably of a frequency of 100 ~. *E* produced the standard, of 2.0 sec. duration, and started the reproduction by means of a key, and *O* stopped the reproduction. The error was always negative and ranged from 0.245 to 0.735 sec. (**10**).

Edgell, reporting in 1903, used the method of reproduction with filled intervals ranging in duration from 0.255 to 6.522 sec. The sound which filled the intervals was produced by induction currents at the rate of 50 per sec. and was transmitted through a receiver. The time between standard and reproduction was about 0.5 sec. The error was positive for intervals from 0.2 to 1.5 sec. duration, and negative for those from 2.0 to 4.0 sec. A good deal of individual variation was found (**7**).

Wrinch, in 1903, used as filling tones from a tuning fork carried through a telephone. The intervals were 0.5 to 1.5 sec. He employed the method of mean gradations, with three intervals, and obtained only positive errors. He believed that no indifference zone will appear with tonally filled intervals, but possibly he had insufficient foundation for such a belief, because he had used no durations above 1.5 sec., which might well chance to be below the indifference zone of the three *O*s who participated in the experiment. No analogy can be drawn between his experiment and *Meumann's* because *Wrinch* did not use unfilled intervals in any form, whereas *Meumann* always used them in pairs with the filled intervals (**58**).

Lobsein's subjects were boys in the fifth year in school. The source of sound was a bell actuated by a key and enclosed in a

box, damped with rubber to give a homogeneous sound. *E* gave the normal time, of 2.0, 5.0 or 10.0 sec. duration, by means of the key, and after 5.0 sec. *O* repeated, using the same key. Click-limited intervals were also reproduced by the same method. In this respect the procedure is more nearly comparable to that followed in the present experiment than that of any study reported here. For this reason the constant errors for the eight *O*s for the 2.0 sec. interval will be presented in tabular form (19, 346):

O	Ah.	Be.	Sö.	Hi.	Ho.	Tr.	Mi.	Sch.
Type of int.								
Filled	+1.8	+0.3	+1.4	+0.8	+1.3	+1.0	+0.9	+2.2
Click-limited	+2.5	+2.0	+1.1	+2.8	+3.7	+3.0	+1.6	+2.2

It will be noted that with the exception of *O*s Sö and Sch. the error is always less for the filled intervals than for the unfilled click-limited intervals; therefore, the filled intervals have shorter reproductions.

Curtis, in a study reported in 1916, was chiefly interested in the secondary criteria used in the estimation of filled and unfilled intervals. She employed the method of constant stimuli with standard intervals of 1.0, 1.5, and 2.0 sec., filled with sounds from a 254 ~ electrically maintained fork, transmitted through a telephone receiver. No constant errors are reported. Like *Meumann* she found overestimation of filled intervals when these were given first with an unfilled interval in the second place. But in the reverse order there were many individual differences in *O*s (3, 13–21). The introspective records showed that the individuals differed more in the secondary criteria used in the estimation of unfilled than of filled intervals. She concludes

> "that the wide individual variations . . . are probably referable to some peculiarity of carrying over an 'empty' time to be compared with the filled. It will be remembered that the different observers used a variety of methods, differing from observer to observer and for one observer from day to day; and it seems natural that such a range of possible representations of the first member should result in widely divergent results. . . . *Katz* insists (13, 312, 324, *etc.*) that it is possible to compare the results of different observers only when we have found the interval most advantageous for each and when we require every observer to behave in the same way in the interval between the members; one should not be allowed to call up the first member in imagery while another does not, and so on" (3, 22).

In a group of series in which the *O*s were instructed to take a passive attitude, and not to "lay off" the first on the second member, the judgments were less accurate. These instructions are similar to those used by *Meumann* and *Curtis* feels that this instruction explains the fact that *Meumann's O*s did not observe strains. In some cases the secondary criteria dropped out altogether, a fact which leads *Curtis* to conclude that they are not indispensable aids to the estimation of time.

Two other workers who were primarily interested in the use of secondary criteria were *Quasebarth* and *Kircher.* Both employed methods of judgment with irregular variation of the compared interval which always followed. Both standard and compared times were filled in both experiments and each worker gave both optical and acoustical series. *Quasebarth,* in 1924, used a 250 ~ electrical fork placed before a microphone. The sound is described as being between a tone and a noise. With a 2.0 sec. standard a positive error was found for the acoustical and a negative error for the optical experiments. All seven of the *O*s had observed tensions of expectation and effort in the optical experiments, but only two observed them in the acoustical experiments, and these tensions were much reduced. When the optical procedure was varied in such a way that the *O*s reported only slight strains the constant error was positive, like that for the acoustical procedure. These facts lead *Quasebarth* to two conclusions, first, that strains are not necessary for time estimation, since the sensitivity is as great when no strains are reported as when the *O*s do observe strains, and second, the presence or absence of strains determines whether or not the second interval will be over or underestimated. The presence of tensions is associated with overestimation, their absence with underestimation of the second interval (**30**, 402–408). He refuses the explanation that the underestimation of the second interval is due to overestimation of the first, because, in the first place, there was no reverberation of the tone in the pause to prolong the standard interval, and, in the second place, the *O*s did not emphasize or concentrate more on the standard

interval, and therefore did not overestimate it. The tone is described by all *O*s as "highly impressive", and therefore its apprehension is simpler than that of the light. It rises with greater force. But the second tone is already known, it rises less impressively than the first, and is faded in comparison with it. This "lack of self-assertiveness" of the second interval leads to a greater passivity, and also slighter attention to the time (**30**, 409). With a normal time of 4.0 sec. the error for the acoustical procedure became negative. The explanation given is that attention must be most active in the perception of the longer time. Strains of expectation are observed, and these, together with an impression of longness, tend toward overestimation. The same is true for a standard time of 5.0 sec. At 6.0 sec. there is the added fact that the unity of the durational experience disappears—it is not all "present". The only new factor which appears with a standard of 8.0 sec. is that mediate criteria become increasingly important (**30**, 415–421).

Kircher, whose study was published two years later, was principally concerned with the distribution of tensions in the standard and compared times. He used only a standard interval of 2.0 sec. His *O*s on the whole reported greater tension in the second interval. With very intense tones a positive constant error was found, but with slight intensities the sign was negative. In the latter case only part of the *O*s observed tensions, and those who did all had large negative errors (**15**, 109–112). When the series were repeated with the instruction to accent the standard interval the signs of the constant errors for both great and slight intensities were reversed (**15**, 119–122).

In a study published in 1928 *Woodrow* investigated the influence of the duration of the initial and terminal sounds upon the estimation of short unfilled intervals. The limiting sounds were produced by a buzzer of a frequency of 1700 ~, which gave a smooth tone with no initial or final clicks (**57**, 168). Experiments were conducted both with the method of constant stimuli and with that of reproduction. The results from the experiments with the method of constant stimuli showed that lengthening

either the initial or terminal sounds caused the interval to be judged longer. *Woodrow* gives the following explanation:

> "One's reaction is to some extent always a reaction to the temporal form as a whole. It thus happens that one gains an impression of total length, with the knowledge that there was an interval, but no very accurate impression of its separate length." (**57**, 192)

This first part of the study bears on the problem of the present experiment only in a general way. Certain of the results obtained with the method of reproduction are however, of special interest. The reproductions of the interval were shorter than, or on the average about equal to, the stimulus interval, according to whether the initial sound was shorter or longer than the terminal sound. However, the reproductions of the sounds themselves showed "a very decided tendency to exceed in length the corresponding sounds of the stimulus forms" (**57**, 264–266). Although the filled and unfilled portions of these temporal patterns were not in general of the same duration, since the limiting sounds were from .07 to .60 sec. and the intervals were from .50 to .80 sec., it may be said that the filled intervals tended to be reproduced longer than the unfilled. This is opposite to the results of *Lobsein.*

In summarizing the work with filled intervals it may be said that in general the smaller times tend to have positive, the larger to have negative errors. Only one *E, Lobsein,* gave both filled and unfilled intervals to the same *O*s in separate series. This would appear to be an ideal procedure in view of the complicating factor of position introduced when a filled and an unfilled interval are presented together for comparison, as in the experiments of *Hall* and *Jastrow, Meumann,* and *Curtis.* These investigators found that the filled intervals were overestimated in comparison with the unfilled when they preceded the latter in the comparison, but the factor of position obscured the true relationship of the two types, because when the order was reversed the result was in some cases also reversed, and in some cases merely confused—*i.e.,* individual differences seemed to be increased (*Curtis*), the effect of the duration of the standard interval became irregular (*Meumann*), or the illusion was destroyed (*Hall* and *Jastrow*).

A further point of importance is that the results presented above are practically all based upon averages and that in many of the studies individual differences existed which were obscured by the averages. These individual differences have not been definitely correlated with specific differences in procedure or attitude, but the probabilities are that they do correspond to differences in attitude and imagery. *Meumann, Quasebarth,* and *Kircher* all appear to have concluded that overestimation is associated with a greater energy of application of attention, but it is apparent that the factors which determine this must vary to some extent among individuals.

The method of reproduction in temporal experiments. There are two questions which may be raised in connection with the use of the method of reproduction in temporal experiments. The first is in connection with its applicability, the second in regard to the interpretation of the constant error obtained from such a method in comparison with the constant error of the judgment methods.

Vierordt first used the method of reproduction in time experiments in 1868 and was criticized by *Wundt* on the grounds that, owing to the time necessary for reaction, the sound is not produced at the moment when it is desired (**26**, 507). *Vierordt* replied that the reaction time was not long enough to matter and that, in any case, when an intermediate time was used between stimulus and reproduction, so that *O* must make one movement for the beginning and a second for the ending of the reproduced interval, the reaction times for the two movements would cancel each other (**50**, 398–399; **26**, 509). *Glass* criticized the method on the same grounds (**26**, 514), and *H. C. Stevens* in reply cited the work of *Martius,* published in 1889, to the effect that it is possible to keep time by pressing a key with the sound of heart beats, with a very slight variable error, some of which can be accounted for by the variability of the heart beat itself (**42**, 2–3; **20**, 546–548). Some light is thrown on the effect of reaction time upon the reproduction by a study published by *Seashore* in 1899. His *O*s had positive errors for standard intervals of .25

and .50 sec. He found that those individuals who had the largest positive errors for the shortest interval also tended to have long reaction times. But he believes these errors are

> "not due to inability to act quickly enough, because two taps can be made in as rapid succession as a series of taps can be made, and no one required more than 0.20 sec. for the complete movement in tapping, which was exactly the same as the movement in the signalling in this test" (37, 80–81).

The objection to the method of reproduction on the grounds of reaction time would indeed appear to be invalid, in those cases where an intermediate time is used, necessitating two reactions on the part of *O*, the time of the second cancelling that of the first, as originally suggested by *Vierordt*. The fact that negative errors for small times do exist is evidence in favor of this conclusion.

A second possible objection to the method of reproduction, which the writer has not found advanced by any investigator, has been suggested by a recent study by *Weber* on the reproduction of durations under load. The results showed that the reproduction of a standard click-limited interval of .55 sec. became longer as the load became heavier on the carriage which *O* was required to move to reproduce the clicks. The loads used varied from 50 to 250 grams (52, 601–602), and the errors increased from +.244 sec. with the lightest load to +.466 sec. with the greatest load. A possible source of error is introduced here, in that the key presents a slight load which was not present in the standard interval. Care is taken, however, to make the load of the key as slight as possible and it seems probable that it is not sufficient greatly to increase the time of the reproduction. Here again the fact that negative errors do exist is evidence that this factor is not a serious drawback to the method.

A final criticism of the method of reproduction pertains to its relation to the methods of judgment. This criticism was urged by *Schumann,* who objected that the variable error of the method of reproduction is large where the difference limen of the judgment methods is small, and that the psychological processes of comparison and of reproduction of small times are different (35). *Meumann* quotes these objections and answers them. In the

first place, he says that it is a mistake to say that no comparison enters into the reproduction of an interval, for in reality we compare each stage of the reproduced time with the corresponding stage of the standard time. He believes that in the judgment methods there is also an element of reproduction, so that the real difference between the two methods is in reality one of emphasis, rather than an utter difference of psychological processes. For that matter, he says, there is some difference of psychological processes in the two judgment methods themselves (21, 481–482). He believes, however, that in reality one method can not be used as a standard for another, and that each has its own sphere of validity (21, 470, 481).

The reason for the use of the method of reproduction in the present experiment was stated in a previous section. On the basis of the above review of the historical discussion of the method its use in studies of temporal estimation seems to be justifiable. Some question may still arise, however, in regard to the interpretation of the signs of the constant errors of the reproduction method when we wish to speak of the results in terms of perception—*i.e.,* in terms of over- and underestimation. So far it has been assumed that a positive error means underestimation of the second interval, or overestimation of the first. With the judgment methods the justice of this interpretation is clear, and with a few exceptions the investigators have held to this usage. In the judgment methods a positive error means that the compared interval which was judged by *O* to be equal to the standard interval is objectively longer than the standard, and that therefore *O* had underestimated it in judging it to be equal to the standard. Just the reverse is true in the case of a negative error. The question is whether the same line of reasoning may be applied to the interpretation of the errors from the method of reproduction. A positive error means that the reproduced interval was longer than the standard. Is this to be interpreted to mean that as *O* reproduced the interval he underestimated its duration and therefore made the reproduction too long? This was the interpretation of the constant error of the

method of reproduction as introduced by *Fechner,* in its application to visual extents and the same interpretation has generally been applied to the error in the method of reproduction as used in the temporal experiment. There has been little discussion of it, however, and a few authors assume that a positive error of reproduction means overestimation of the interval. *Woodrow* is the only author to present constant errors both for a judgment method and the method of reproduction, obtained under comparable conditions. As a matter of fact, his results for the two methods are not strictly comparable, after all, because in the judgment method the standard and compared intervals were of different forms, but the conditions were more nearly alike than in any other two groups of data from the two methods. As to the interpretation of the error from the judgment method *Woodrow* says:

"It is not self-evident that a subject who, in reproducing an interval, makes it longer than it objectively was has overestimated the objective interval; for it may be that the subject intended to, and believed that he had, set up in reproduction a much shorter interval than he actually had. The same illusions that occur in connection with listening to the temporal forms may occur in connection with their reproduction" (57, 261).

Woodrow's results, however, do not confirm the interpretation of the constant errors of both methods by the same rule. The intervals presented in the form *l-s* were reproduced longer than those in the form *s-l,* and this, according to the interpretation given above, would mean that the intervals in the form *s-l* were overestimated in comparison with those in the form *l-s.* But in the method of constant stimuli it was found that *l-s* was overestimated in comparison with *s-l* — *i.e.,* "the interval in *s-l,* when compared with one of .50 sec. in the form *l-s,* had to be made 33 per cent longer before being judged equal" (57, 264). This would indicate either that the use of two forms in one comparison obscured the true relationship of the estimation of the two forms, by the effect of order, or else that the error from the method of reproduction can not be interpreted according to the same rule as that of constant stimuli. It has been shown that in the work of *Hall and Jastrow, Meumann,* and *Curtis,* order was a

disturbing factor when intervals of two types were used in the same comparison. Results to be presented later in the present study tend to show that a positive error of reproduction does mean underestimation and a negative error overestimation, as suggested by *Woodrow* in the quotation on the previous page. If this interpretation is correct it appears probable that the effect of order, brought about by the use of two forms in a single comparison, has obscured the true relationship of over- and underestimation in *Woodrow's* experiments. So far it does not seem possible to make a final choice between the two proposed interpretations of the constant error of the method of reproduction. Indeed, it is possible that two influences may be at work, which in some cases might cancel each other and in some cases work together.

III. Technique

Apparatus. The requirement of this experiment for a source of sound which would produce a number of homogeneous tones of different pitches was met by the use of the Western Electric 2-A audiometer. The following four frequencies were used in the course of the experiment: 128, 256, 512, and 1024 ~. For all frequencies the ammeter was set at the point on the dial where oscillation first became steady. The potentiometer for the regulation of intensity was set at 80 sensation units for each of the frequencies, with the exception of that of 128 ~, for which it was set at 65.[4] The tones produced by this audiometer are not pure tones, but rather rich. The receiver which belonged to the audiometer was retained, but a new cord and plug were used. The cord was cut and a mechanical means of interrupting the sound in the receiver was introduced between the audiometer,

[4] This was the greatest intensity at which it was possible to set the frequency of 128 ~, but when the other frequencies were set at this point the tones sounded much weaker than did the tone corresponding to 128 ~. It seemed to *E* that when they were set at 80 the three tones sounded about as intense as did the tone corresponding to 128 ~ at 65. The *O*s varied in their ranking of the intensities of all pitches with the exception of that corresponding to 512 ~, which seemed the most intense to all *O*s. A sensation unit is approximately equal to the smallest change in intensity that can be heard by the normal ear.

which was in an outer experimental room, and the receiver, which was in the sound-proof room, where *O* was seated.[5]

It was found necessary to break both wires of the circuit from the audiometer to the receiver because when only one was cut oscillations were picked up by the remaining wire. *O* heard this as a very faint tone of the same pitch as that which was plugged in on the switchboard of the audiometer.[6]

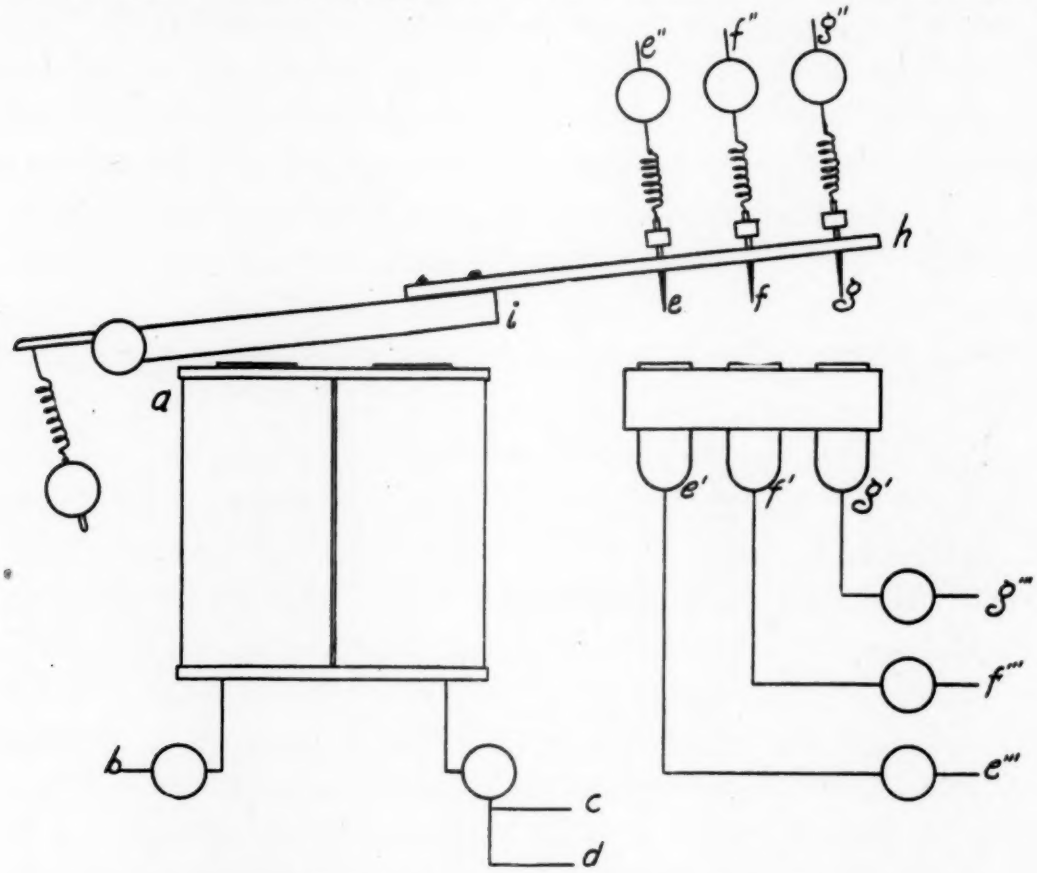

FIG. 1. Diagram of contact device on electromagnet.

a, electromagnet from which wires led, *b* to dry cells, *c* to contacts on the *Zeitsinn Apparat*, and *d* to *O*'s key; *e*, *f*, *g*, sharpened and amalgamated copper points which rode on wooden extensions, *h*, of clapper, *i*; these dipped into mercury cups *e'*, *f'*, *g'*, when the clapper was down, and were connected to binding posts which led wires *e''* and *f''* to the receiver, and *g''* to the magnet marker; *e'''* and *f'''* likewise went to the receiver, and *g'''* to the marker.

[5] For certain control series in which the unfilled intervals were bounded by clicks instead of continuous tones the apparatus used was a telegraph sounder. This was inserted in place of the receiver in the sound-proof room and was set out of sight under *O*'s chair. In place of the audiometer in the outer room two dry cells were inserted. A slight defect was present in this set-up, namely, that it was found impossible to make the clicks produced by the make and break of the circuit sound exactly alike. The differences were qualitative rather than intensive.

[6] Some *O*s still heard a very faint tone at times but it is believed that this was subjective, and not due to any external source.

The two wires from the audiometer were led to the base of two mercury cups. Into these cups dipped simultaneously two sharpened and amalgamated copper wire points, which were attached to plungers on a wooden extension of a clapper adapted from an electromagnetic gong. A third mercury cup and a third plunger with wire point on the clapper were in circuit with two dry cells and a magnetic marker by means of which the falling or rising of the clapper and the consequent production or interruption of the tone in the receiver were recorded. Fig. 2 shows a complete diagram of the electrical connections and Plate I shows the actual arrangement of apparatus in the outer experimental room.

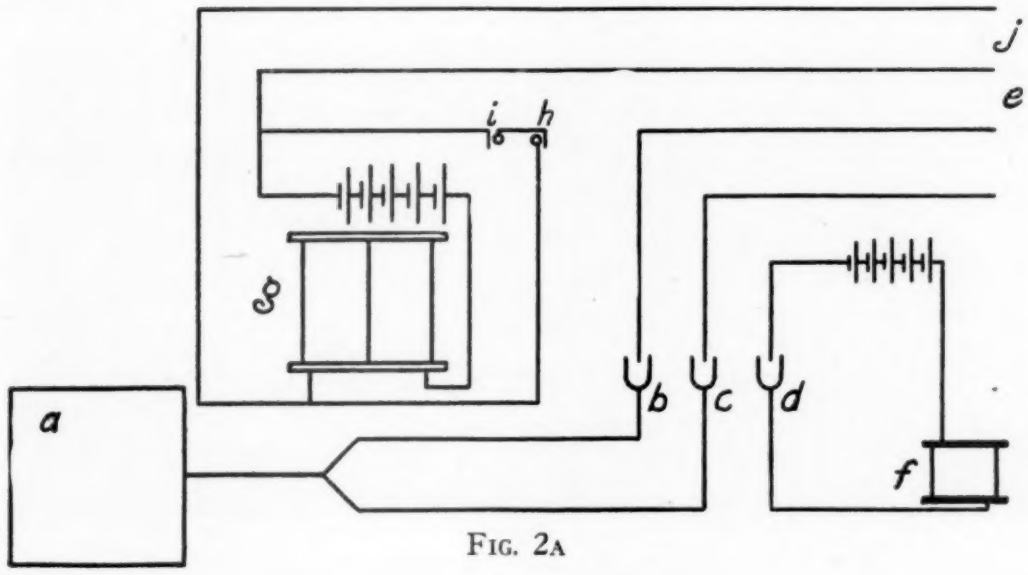

FIG. 2A

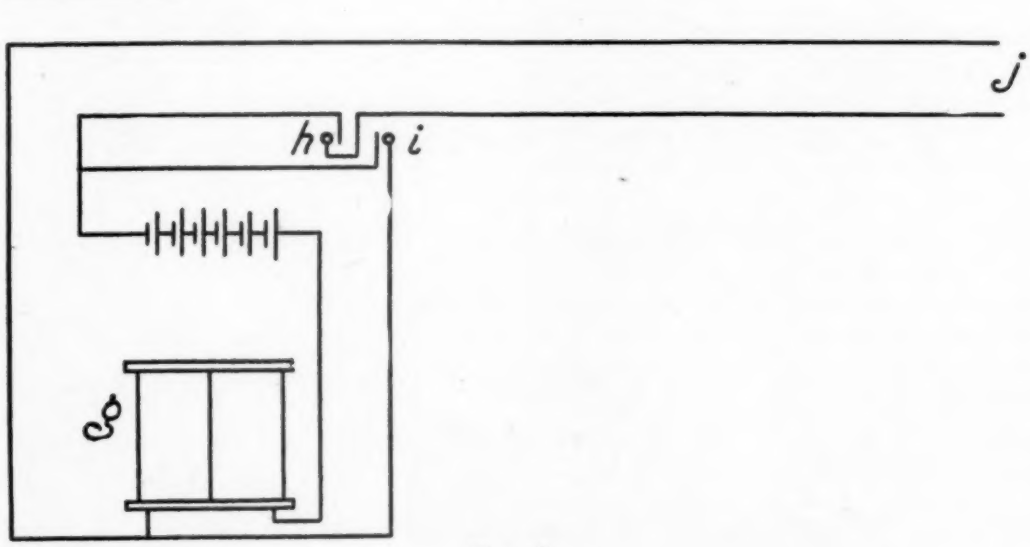

FIG. 2B

FIG. 2. Wiring diagram.

a, audiometer, *b* and *c*, mercury cups in circuit between audiometer and receiver, *e*, in sound-proof room; *d*, mercury cup in circuit with magnet marker, *f*, which made record on kymograph drum; *g*, electromagnet in circuit with dry cells and with contacts *h* and *i* on the *Zeitsinn Apparat*, and with *O*'s key, *j*, in sound-proof room; A, arrangement for filled intervals, B, arrangement for unfilled intervals.

The electromagnet bearing the mercury contacts which controlled the opening and closing of the audiometer circuit was in turn controlled in two ways: either by the timing device for the production of the standard intervals, or by *O*'s key on the switchboard in the sound-proof room. The timing device consisted of two especially constructed contacts mounted on the rim of the Leipzig *Zeitsinn Apparat*[7] which was in gear with a Ludwig-Balthsar kymograph. The contacts were attached to the rim of the apparatus by hard rubber mountings similar to those pictured by *Titchener* (**47**, 399). The mountings were grooved to fit the rim of the apparatus and might be moved to any position on the dial and fixed by means of a screw in any desired

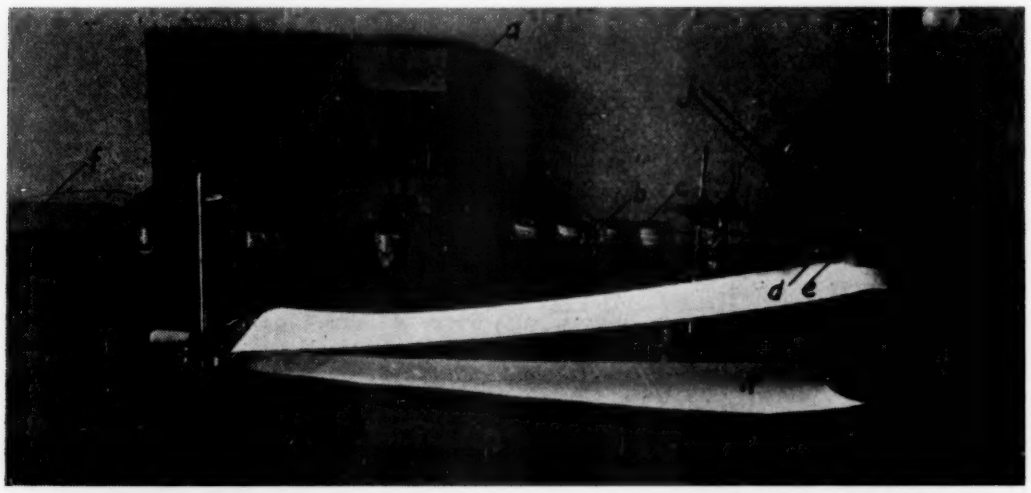

PLATE I. Apparatus in outer experimental room.

a. audiometer.
b. electromagnet.
c. mercury contacts between receiver and audiometer, and for marker.
d. marker in circuit with mercury contact on electromagnet.
e. Marker in circuit with 10 ~ tuning fork.
f. ten ~ tuning fork.
g. Ludwig-Balthsar kymograph.
h. recording drum.
i. revolving pointer of the *Zeitsinn Apparat.*
j. contacts in circuit with electromagnet.
k. contacts which control signal light.

position (Plate I, J). The two contacts differed slightly (Fig. 3). Contact A was constructed so that when it was set the circuit was not continuous through it. The passage of the revolving pointer of the apparatus released a catch on the contact so that one end of a small lever might be pulled over onto a contact area by a spring which served the double purpose of pulling over the lever and of leading the current into it. Contact B, on the other hand, when set produced a closed circuit. In this position the end of the small lever rested upon the contact area. But when the pointer struck this contact the small lever was pulled away from the contact area by the spring and the circuit was broken.

[7] This apparatus is illustrated by *Titchener* (**47**, 399) and is described and illustrated by *Wundt* (**59**, 502–505).

In those series in which the standard interval was a filled duration Contact A was placed so that it would be struck first by the revolving pointer and the two contacts were placed in circuit with each other and with the electromagnet (Fig. 2, A). In those series in which the tone was sounded continuously and the intervals were cessations of the tone, Contact B was placed so that the pointer struck it first. It was in circuit with the electromagnet, independent of the other contact, A, and when it was set the circuit was closed and the tone sounding. Contact A, in the second position, was in circuit with the electromagnet through the same circuit with which *O*'s key was connected (Fig. 2, B). After the opening of the circuit by the release of the first contact, the release of the second contact, A, closed the circuit again,

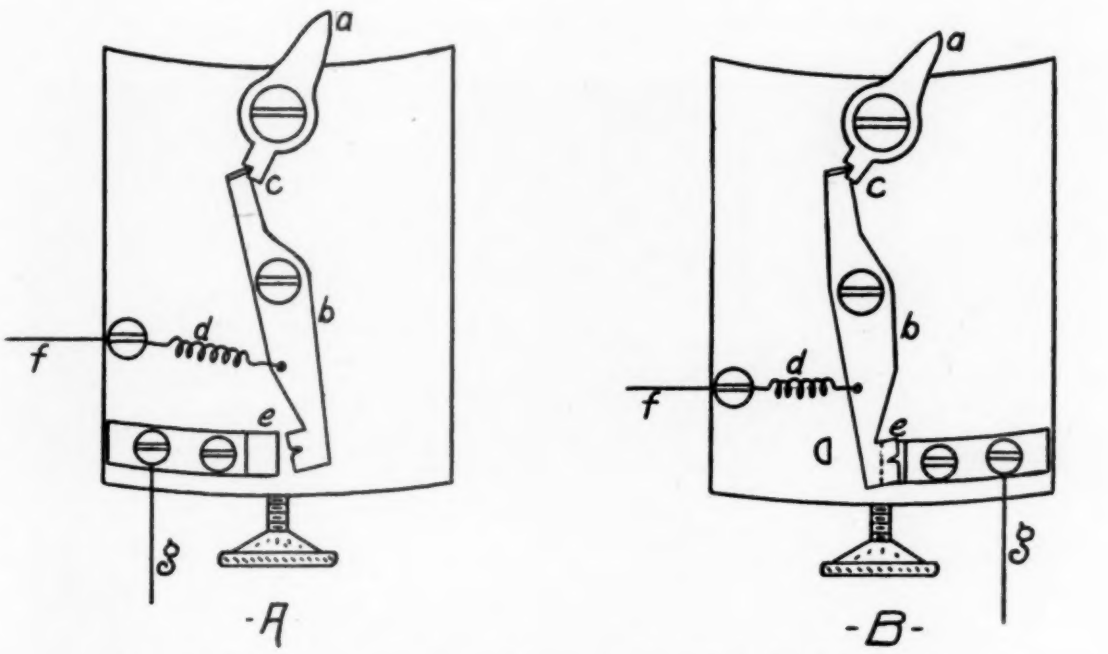

FIG. 3. Diagram of contacts for control of standard interval.

a, lever which was struck by revolving pointer of *Zeitsinn Apparat*, thus releasing lever *b*, which had been held by the catch at *c*; the spring *d* then drew the second lever onto the contact area *e*, in the case of Contact A, or off of it in the case of B; *f* and *g*, wires to dry cells and electromagnet.

but this time through the circuit to *O*'s key. *O* might then break the circuit with his key in order to reproduce the empty interval.[8]

The speed of the kymograph was so adjusted that the pointer of the *Zeitsinn Apparat* made one revolution in six seconds so that 60 degrees represented one second. The first contact was always left at the zero position and only the second adjusted when it was necessary to change the duration of the interval.

[8] There was always a certain impact noticeable by the listener coincident with the cessation of any tone. Inasmuch as the current through the electromagnet was the same, whether controlled by the contacts on the *Zeitsinn Apparat* or by *O*'s key, the impact in the standard must have been objectively the same as that in the reproduction, although some *O*s at times thought the two impacts sounded different.

The key by means of which *O* reproduced the standard intervals consisted of the lever of a telegraph key, which swung on two posts, through one of which it was connected by a wire with the circuit of the electromagnet (Plate II). Between this fulcrum and the end which was pressed by *O*'s finger was a contact point which dipped into a mercury cup. Likewise at the other end of the lever was a contact point and mercury cup. When the key was in its natural position this second point rested in its mercury cup and the first point was separated from the mercury in the cup below it. When *O* pressed the key the first point dipped into the mercury and the second was lifted from it. Thus a make-break or a break-make arrangement was made possible. The former was used in the filled intervals, the latter in the unfilled intervals.[9] The quickness of action of the key was obtained by means of a spring between the first cup and *O*'s finger and by rubber bands which held down the far end

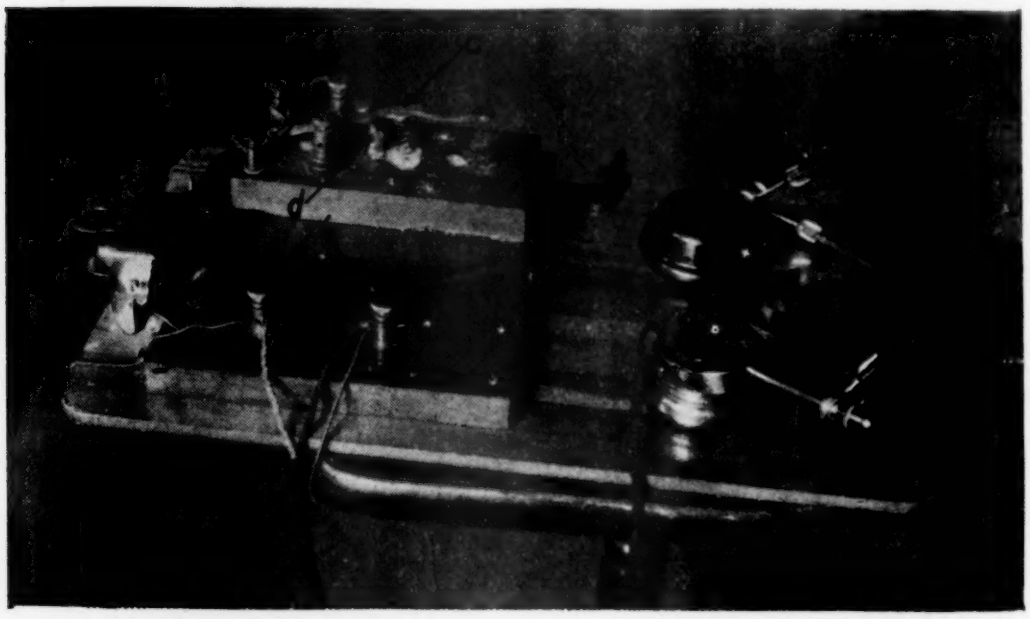

PLATE II. *O*'s receiver key.

a. receiver.
b. binding posts connecting receiver with mercury contacts on electromagnet, and with audiometer.
c. *O*'s key.
d. mercury cup used in make-break arrangement.
e. mercury cup used in break-make arrangement.

of the lever. A pad of felt under the end of the key pressed by *O* regulated its excursion.

It seemed desirable to use for the graphic record the drum of the same kymograph that was used to drive the *Zeitsinn Apparat.* In order to do this it was necessary that the drum should be in a horizontal position and that it revolve at a slower speed than the pointer of the *Zeitsinn Apparat.* Therefore, instead of the cogwheel already on the kymograph, a wheel larger in diameter was substituted and geared into the *Zeitsinn Apparat,* which was

[9] There was always a spark and a slight snap in the mercury cup when the circuit was broken.

screwed onto an L-shaped standard, the base of which was screwed onto the base of the kymograph stand. The face of the *Zeitsinn Apparat* was thus vertical instead of in its usual horizontal position (Plate I). The number of cogs on the new wheel was such that the pointer on the *Zeitsinn Apparat* revolved only once to 2.65 revolutions of the wheel on the kymograph. The next to the highest speed of the kymograph clockwork was used, and the small friction wheel was adjusted to a position not far from the center of the larger wheel—indicated by the small pointer as just above one on the scale.

The graphic record was kept on a strip of paper five and one-half inches wide which rolled over the drum of the kymograph on the one hand, and on the other, at any desired distance from the drum, over a small roller clamped to a standard. The production and cessation of the tone in the receiver were recorded by means of a small electric signal attached to a third mercury contact on the electromagnet, as described above. A second electric signal was in circuit with a ten ~ tuning fork, electrically maintained. The marking was done by two glass capillary pens. The blade of the signal which recorded the standard and reproduced intervals was extended by means of a copper wire which was bent over toward the marker which made the time line, so that the records of the two pens were made only about a quarter of an inch apart.

The warning signal before the standard interval and the signal for reproduction were given by a small electric light. This was controlled by means of two switches on the rim of the *Zeitsinn Apparat*. These switches were similar to the Meumann contacts pictured by Titchener (**47**, 399) except that on one of them the first prong was filed off. The remaining prong of this contact was the first to be struck when the pointer of the apparatus was set in motion for an experimental trial. When this was struck the small light in the sound-proof room was turned off. The two sound contacts were then set off in turn, thus producing the standard interval. Finally the revolving pointer struck the second light switch, which was so constructed that it closed the light circuit momentarily, thus giving a flash of light as a signal to *O* to press his key for the reproduction. After the reproduction *E* turned on the light again by reclosing the first switch. *O* was provided with a third switch with which he could signal to *E* by flashing a light on *E*'s table. Except for the signal light the sound-proof room was dark during the experimental trials.

Observers. There were 17 *O*s, to whom the letters A to Q have been assigned. A, B, C, D, and G were advanced graduate students in the department of psychology at the University of Iowa. E and F were graduate students in other departments who were enrolled for advanced courses in psychology. The remainder of the *O*s were students enrolled in the course in elementary psychology in the summer session. A, F, H, I, J, L, O, P, and Q were women. In age, I and O were above the other *O*s, who were between the ages of 20 and 35, approximately. A and E were both highly trained on the piano and organ and G, K, L, and M may likewise by designated as "musical *O*s." The remaining *O*s had had no extensive musical

practice or interest. A, B, C, D, E, and G were considered relatively practiced or experienced *O*s. The remaining *O*s were quite inexperienced.

Procedure. In the greater part of the study the tone used corresponded to 256 ~ and the standard intervals centered about 1.5 sec. duration. Other durations used as standard intervals centered about 0.5 sec. and 2.5 sec., and three other pitches were used in some series, namely, those corresponding to 128, 512 and 1024 ~. There was an advantage in the slight variation in the standard which appeared especially in those series in which only one of the three principal durations was used—that is, *O* had to listen to each standard separately rather than to reproduce an ideal duration or to slip into a rhythmic or automatic response.

In choosing the three principal standard durations for the study three criteria were considered. We wished to use durations which should be within the range of durations of musical notes, which should be within the category known as "short times", and which should present considerable range within this classification. In connection with the first criterion it was found that on a standard metronome the range of durations for the quarter note from *presto* to *largo* was 0.28 sec. to 1.4 sec. Likewise the metronome markings on a number of compositions of *Haydn* and *Debussy* were investigated. These varied from 0.42 sec. for *allegro* to 1.30 sec. for *largo* given as the duration for the quarter note. Half and whole notes would extend the range of durations of musical notes well beyond the longest duration chosen for this study—*i.e.,* 2.5 sec. The determination of the limits of the classification "short times," as used in psychological experimentation, is more difficult. The times here used are short in comparison with durations of 30 sec. or more, which have been used by a number of investigators for the study of the effect of filling intervals with various types of mental work. However, the range from 0.5 sec. to 2.5 sec. covers completely *Benussi's* three classes of subjectively short, indifferent, and long times (2), and includes *Meumann's* short and medium times (22, 23). It is convenient to accept the former of these two general inter-

pretations of the term "short times" in order to satisfy our second criterion, and the latter in fulfilling our third criterion in regard to range of durations.

In all series, regardless of the duration of the standard interval, the light in the sound-proof room was turned off 1.8 sec. before the standard interval was given. Just before the light went off *E* always flashed it quickly by hand as a warning to *O*. The final turning off of the light and the signal for reproduction were controlled by the rotation of the pointer on the *Zeitsinn Apparat,* as described in the section on apparatus. The signal for reproduction always came one sec. after the close of the standard. It was considered advisable to use such a signal in order to make the intermediate time between standard and reproduction as nearly as possible equal for all *O*s.. Without it some *O*s tended to wait the time of the standard duration before reproducing. It is true that the quickness of reproduction after the signal also varied among the *O*s, but the pause required by the use of the signal made this difference a smaller part of the whole. The choice of the duration for this pause was somewhat arbitrary. The writer was not successful in finding a definite statement of the length of duration of the memory after-image for tones. The work of *Schumann* (35), *Thorkelson* (21), *Aliotta* (1), *Wolfe* (53) and others upon the effect of the length of the intermediate time in the methods of constant stimuli and minimal changes is not quite applicable in this connection. *Vierordt,* using the method of reproduction, found a different indifference time when he used an intermediate time and when he used none (50, 397). *Paneth* studied the very point which interests us in connection with the method of reproduction. His *O*s reproduced by two pressures of a key standard durations which varied from a small fraction of a second to five minutes. The intermediate times also varied within the same range. His conclusion is that

> "the sharpness of the memory image for such a time interval in the course of five minutes decreases so slightly that the decrease can not be certainly determined by this method" (27, 82).

He states that *R. Wahle* tried the same experiment with the same negative results.

In those series in which the tones from the audiometer were used four types of series were possible for filled and unfilled intervals alike. First, duration might be held constant while the pitch of the filling or surrounding tone was varied; second, duration of the interval might be varied while the pitch was held constant throughout the series; third, the factors of pitch and duration might both be varied; and fourth, both factors might be held constant. In division I of the experiment all four of these types of series were used with filled and unfilled intervals. No click-limited intervals were presented. *O*s A, B, C, D, E, F, and G participated in this part of the experiment. In division II, which took place at a later date, both pitch and duration were held constant in the filled and unfilled intervals. The pitch corresponded to 256 ~ and the duration was 1. 5 sec. Click-limited intervals of 1.5 sec. duration were likewise presented for purposes of control. All of the *O*s except B and F took part.

In those series where any factor was varied the order of appearance of each pitch or duration, as the case might be, was determined by lot, except that all variables were used as nearly as possible an equal number of times and that the chance order was re-arranged somewhat so that each variable would follow each other variable and itself at least once. The number of trials in each series was 27 in division I, and varied from 20 to 40 in division II.

When two series were given in one experimental period—about an hour—the total number of trials did not amount to more than 50 or 60 and *O* always came out of the sound-proof room for a brief period of relaxation between series. Likewise in series in which the intervals were gaps in a continuous tone, a rest period was given between each seven or nine trials. This was done in an attempt to keep the tone from becoming annoying and thus introducing an affective factor which was not present in the case of the filled intervals. In those series of unfilled intervals in which the pitch of the limiting tone was varied there was of course necessarily a brief cessation of the tone between trials. This change in pitch was always made immediately after the

close of a trial, so that *O* might become accustomed to the new pitch during the time in which *E* was making the other adjustments of the apparatus.

With *O*s A to G an entire period was given to practice before the first record was taken and before the series with unfilled intervals were begun. In the case of the remaining *O*s only part of a period was used for the preliminary practice. In all cases ten or twelve practice trials were given before each regular series.

The instructions were typed on a card and presented to *O* to be read. The instructions for filled intervals were as follows:[10]

> A short time after the light goes off you will hear the standard tone in the receiver. A flash of the light will then be a signal for you to reproduce the duration of the standard tone *as exactly as you can* by pressing the reaction key and releasing it again after the tone has lasted as long as the standard lasted. In the reproduction *concentrate your attention upon the tone* heard rather than upon the manual act. Take a strictly objective attitude—pay strict attention and strive for accuracy. Do not count.
>
> *Practice period*
>
> Practise the use of the key, striving to make the sound correspond to the standard. Work to make the use of the key automatic, so that in the experimental series your attention may be directed to the sound of the standard and of the reproduction.

The instructions for unfilled intervals were similar except for the first two or three sentences,[11] which were stated as follows:

> In this series you will hear a tone sounding continuously. The standard interval will be a cessation of the tone. After the light flashes you are to reproduce the duration of this cessation, by pressing the key.

The first sentences of the instructions for the unfilled intervals bounded by clicks were:

> A short time after the light goes off you will hear two clicks. A flash of the light will then be a signal for you to reproduce the two clicks by pressing the key for the first click and releasing it for the second. Reproduce the duration between the clicks *as exactly as you can, etc.*

In the experiments of division I an additional paragraph appeared in the instructions, as follows:

[10] In the preliminary experimentation, the signal for reproduction was not used, and the instruction was to "reproduce immediately." All the data used are taken from experiments with the warning signal.

[11] The instructions in full may be found in the protocol.

After the light comes on record the degree of your confidence in the accuracy of your reproduction, letting 1 represent a high degree of confidence, 2 average, and 3 doubtful.[12] Make and record introspective observations regarding your method of judging how long to make the second tone, its accuracy, *etc.*

In this way the *O*s were encouraged to give as much attention to introspective observations as they felt would not interfere with the series, but all *O*s were told that a special time for introspections would be given later and that if the process of introspection tended to become distracting it might be abandoned during the regular series.

In addition to the judgments of degree of accuracy of the reproductions and the voluntary comments of the *O*s introspective material was obtained from a number of *O*s by means of a questionnaire, which may be found in the protocol.

B and E read this outline after finishing their repetition of series 8, and used it as a guide in writing their introspections in special series which were given them at that time. B, C, D, E, and G also wrote reports based on the outline at the end of their work in division I. In division II, after each *O* had finished the series assigned to him, *E* asked each a number of questions and took careful notes of the responses. These questions may be found in the protocol.

IV. Discussion of Results

The central problem of the study may now be restated as follows: Does the type of pattern, filled intervals, or unfilled intervals, affect the reproduction? A subordinate question is: Does the pitch of the surrounding or filling tone make a difference in the reproduction? Can any principle of explanation be found for the result obtained in the attempt to answer these questions?

[12] Special forms were made out for the recording of these judgments of certainty, in order that *O* might always write his judgment opposite the proper trial. Because he had this form before him *O* always knew just how many trials there were to be in the series. This was not the case in the series of division II, in which no judgments of accuracy were made and in which *O* had no knowledge of the number of trials yet to be given him before the end of the series.

The effect of any pattern upon the reproduction will be evaluated in terms of the constant error and of the standard deviation of the distribution of errors. The constant error represents the average of the individual errors made by any *O* in all trials for a specific pattern and pitch. An individual error is positive if the reproduction was longer than the standard and negative if the reproduction was shorter. The constant error is correspondingly positive if the reproductions were on the average longer and negative if they were on the average shorter than the standards. An additional question arises in the interpretation of the constant error: does a positive constant error mean that the interval has been overestimated or underestimated? Finally, in comparing the results of this study with the scores from the test for the sense of time in the Seashore Measures of Musical Talent it will be necessary to consult the standard deviations of the distribution of errors, in order to determine the accuracy of reproduction of the various types of intervals.

The relationship between pitch and constant error. The following tables, I to VI, give the constant errors from data for all *O*s for filled and unfilled intervals in all the pitches and durations used.[13] Under the column headed "Mean CE" the average of

TABLE I. *Constant errors for filled intervals:* 0.5 *sec.*

O	Pitch	No. trials	Mean standard	Mean repro.	Mean CE
A	128	2	0.56	0.61	+.05 ±.000
	256	6	0.53	0.54	+.01 ±.018
	512	3	0.60	0.61	+.01 ±.013
	1024	2	0.57	0.60	+.03 ±.011
C	128	3	0.45	0.49	+.04 ±.022
	256	7	0.45	0.43	−.02 ±.015
	512	8	0.45	0.39	−.06 ±.020
	1024	3	0.45	0.35	−.10 ±.002
D	128	14	0.45	0.51	+.06 ±.016
	256	11	0.45	0.52	+.07 ±.037
	512	9	0.43	0.44	+.01 ±.030
	1024	9	0.44	0.50	+.06 ±.022

[13] In all the following tables the data are taken from division I of the experiment, unless otherwise indicated.

TABLE II. *Constant errors for filled intervals:* 1.5 *sec.*

O	Pitch	No. trials	Mean standard	Mean repro.	Mean CE
A	128	6	1.62	1.65	+.03 ±.028
	* 256	41	1.49	1.86	+.37 ±.022
	512	2	1.62	1.72	+.10 ±.016
	1024	5	1.60	1.72	+.12 ±.062
B	128	26	1.41	1.40	—.01 ±.021
	256	46	1.43	1.38	—.05 ±.012
	512	23	1.41	1.41	0.00 ±.022
	1024	21	1.41	1.48	+.07 ±.024
C	128	19	1.43	1.42	—.01 ±.017
	256	13	1.44	1.44	0.00 ±.205
	* 256	81	1.48	1.54	+.06 ±.015
	† 256	94	1.47	1.52	+.05 ±.015
	512	17	1.44	1.39	—.05 ±.016
	1024	18	1.44	1.41	—.03 ±.026
D	128	21	1.46	1.45	—.01 ±.021
	256	9	1.44	1.36	—.08 ±.044
	* 256	36	1.48	1.55	+.07 ±.019
	† 256	45	1.47	1.51	+.04 ±.018
	512	11	1.45	1.40	—.05 ±.034
	1024	14	1.44	1.49	+.05 ±.031
E	128	24	1.42	1.47	+.05 ±.013
	256	75	1.42	1.46	+.04 ±.008
	* 256	29	1.48	1.57	+.09 ±.014
	† 256	104	1.44	1.49	+.05 ±.007
	512	22	1.42	1.55	+.13 ±.018
	1024	21	1.42	1.58	+.16 ±.016
G	128	26	1.43	1.60	+.17 ±.012
	256	26	1.43	1.57	+.14 ±.010
	* 256	99	1.49	1.49	0.00 ±.006
	† 256	125	1.48	1.51	+.03 ±.006
	512	25	1.44	1.55	+.11 ±.012
	1024	25	1.43	1.57	+.14 ±.011
H	* 256	44	1.49	1.79	+.30 ±.022
I	* 256	39	1.46	1.28	—.18 ±.030
J	* 256	40	1.46	1.70	+.24 ±.028
K	* 256	89	1.48	1.60	+.12 ±.010
L	* 256	87	1.46	1.49	+.03 ±.013
M	* 256	98	1.48	1.49	+.01 ±.009
N	* 256	29	1.48	1.68	+.20 ±.022
O	* 256	38	1.46	1.22	—.24 ±.024
P	* 256	37	1.45	1.81	+.36 ±.034
Q	* 256	42	1.49	1.60	+.11 ±.020

* Indicates data from division II.
† Indicates total of data from divisions I and II.

the errors for each section of data is given and each average is followed by its probable error.[14]

TABLE III. *Constant errors for filled intervals:* 2.5 *sec.*

O	Pitch	No. trials	Mean standard	Mean repro.	Mean CE
A	128	6	2.70	2.67	—.03 ±.070
	256	4	2.62	2.62	0.00 ±.061
	512	4	2.57	2.50	—.07 ±.081
	1024	4	2.66	2.61	—.05 ±.071
C	128	10	2.42	2.46	+.04 ±.021
	256	12	2.43	2.44	+.01 ±.039
	512	9	2.44	2.50	+.06 ±.031
	1024	13	2.42	2.51	+.09 ±.027
D	128	20	2.46	2.22	—.24 ±.026
	256	11	2.41	2.44	+.03 ±.051
	512	11	2.40	2.48	+.08 ±.038
	1024	9	2.42	2.44	+.02 ±.057

TABLE IV. *Constant errors for unfilled intervals:* 0.5 *sec.*

O	Pitch	No. trials	Mean standard	Mean repro.	Mean CE
A	128	6	0.49	0.56	+.07 ±.006
	256	6	0.51	0.48	—.03 ±.010
	512	10	0.53	0.57	+.04 ±.011
	1024	7	0.54	0.63	+.09 ±.019
B	128	17	0.54	0.74	+.20 ±.035
	256	21	0.52	0.86	+.34 ±.058
	512	19	0.55	1.12	+.57 ±.071
	1024	16	0.53	0.80	+.27 ±.030
C	128	6	0.57	0.39	—.18 ±.011
D	128	16	0.58	0.66	+.08 +.023
	256	19	0.57	0.60	+.03 ±.015
	512	22	0.57	0.70	+.13 ±.019
	1024	16	0.59	0.69	+.10 ±.030
E	128	21	0.53	0.52	—.01 ±.009
	256	18	0.54	0.53	—.01 ±.008
	512	19	0.57	0.52	—.05 ±.011
	1024	15	0.57	0.54	—.03 ±.010
F	128	7	0.51	0.57	+.06 ±.017
	256	16	0.52	0.50	—.02 ±.014
	512	14	0.52	0.52	0.00 ±.013
	1024	16	0.54	0.56	+.02 ±.016

[14] The following formula was used for the probable error of the average: $PE_M = \frac{.6745\sigma}{\sqrt{N}}$ (9, 125).

TABLE V. *Constant errors for unfilled intervals:* 1.5 *sec.*

O	Pitch	No. trials	Mean standard	Mean repro.	Mean CE
A	128	9	1.48	1.69	+.21 ±.042
	256	9	1.54	1.70	+.16 ±.022
	* 256	42	1.55	1.88	+.33 ±.018
	† 256	51	1.55	1.85	+.30 ±.016
	512	12	1.54	1.79	+.25 ±.040
	1024	7	1.55	1.86	+.31 ±.019
B	128	23	1.58	1.81	+.23 ±.050
	256	44	1.54	2.21	+.67 ±.048
	512	17	1.54	1.94	+.40 ±.064
	1024	16	1.54	1.98	+.44 ±.057
C	128	7	1.53	1.39	—.14 ±.012
	* 256	95	1.57	1.60	+.03 ±.011
D	128	19	1.57	1.60	+.03 ±.025
	256	14	1.57	1.66	+.09 ±.035
	* 256	38	1.56	1.74	+.18 ±.024
	† 256	52	1.56	1.71	+.15 ±.020
	512	16	1.56	1.62	+.06 ±.033
	1024	21	1.58	1.71	+.13 ±.029
E	128	16	1.57	1.41	—.16 ±.020
	256	58	1.57	1.41	—.16 ±.010
	* 256	29	1.55	1.44	—.11 ±.015
	† 256	87	1.56	1.42	—.14 ±.008
	512	18	1.58	1.44	—.14 ±.043
	1024	17	1.56	1.41	—.15 ±.025
F	128	11	1.52	1.63	+.11 ±.021
	256	14	1.56	1.71	+.15 ±.033
	512	16	1.57	1.75	+.18 ±.033
	1024	16	1.58	1.72	+.14 ±.027
G	* 256	90	1.54	1.41	—.13 ±.008
H	* 256	36	1.59	1.75	+.16 ±.024
I	* 256	39	1.55	1.57	+.02 ±.035
J	* 256	36	1.67	2.16	+.49 ±.055
K	* 256	95	1.58	1.68	+.10 ±.015
L	* 256	84	1.56	1.56	0.00 ±.015
M	* 256	102	1.60	1.48	—.12 ±.010
N	* 256	36	1.61	1.86	+.25 ±.018
O	* 256	36	1.63	1.36	—.27 ±.030
P	* 256	15	1.56	1.66	+.10 ±.058
Q	* 256	45	1.57	1.71	+.14 ±.025

Legend same as in Table II.

TABLE VI. *Constant errors for unfilled intervals:* 2.5 *sec.*

O	Pitch	No. trials	Mean standard	Mean repro.	Mean CE
A	128	6	2.39	2.58	+.19 ±.075
	256	6	2.51	2.13	—.38 ±.036
	512	9	2.51	2.27	—.24 ±.045
	1024	6	2.54	2.29	—.25 ±.080
B	128	19	2.58	2.90	+.32 ±.096
	256	20	2.58	2.85	+.27 ±.087
	512	17	2.52	3.06	+.54 ±.097
	1024	17	2.52	3.06	+.54 ±.077
C	128	5	2.50	2.34	—.16 ±.048
D	128	18	2.53	2.20	—.33 ±.053
	256	24	2.53	2.20	—.33 ±.038
	512	16	2.54	2.34	—.20 ±.049
	1024	18	2.56	2.24	—.32 ±.046
E	128	13	2.52	2.06	—.46 ±.027
	256	19	2.57	2.16	—.41 ±.045
	512	16	2.58	2.13	—.45 ±.052
	1024	15	2.56	2.17	—.39 ±.029
F	128	11	2.51	2.65	+.14 ±.025
	256	17	2.57	2.66	+.09 ±.038
	512	11	2.57	2.74	+.17 ±.045
	1024	12	2.61	2.42	—.19 ±.048

TABLE VII. *Influence of pitch on constant errors; filled intervals;* 1.5 *sec.*

O	Compared pitches		Higher pitch longer Diff. PE diff.	Prob.	Lower pitch longer Diff. PE diff.	Prob.
A	128+	512+	$\frac{.07}{.032} = 2.18$	93		
	+	1024+	$\frac{.09}{.068} = 1.32$	81		
	512+	1024+	$\frac{.02}{.064} = 0.31$	58		
B	128—	256—			$\frac{.04}{.024} = 1.66$	87
	—	512o	$\frac{.01}{.030} = 0.33$	59		
	—	1024+	$\frac{.08}{.031} = 2.58$	96		

O	Compared pitches		Higher pitch longer Diff. / PE diff.	Prob.	Lower pitch longer Diff. / PE diff.	Prob.
	256—	512o	.05 / .025 = 2.00	91		
	—	1024+*b*	.12 / .026 = 4.61	100		
	512o	1024+	.07 / .032 = 2.18	93		
C	128—	256o	.01 / .205 = 0.04	51		
	—	512—			.04 / .023 = 1.73	88
	—	1024—			.02 / .031 = 0.64	67
	256o	512—			.05 / .205 = 0.24	57
	o	1024—			.03 / .206 = 0.14	54
	512—	1024—	.02 / .030 = 0.66	67		
D	128—	256—			.07 / .048 = 1.45	84
	—	512—			.04 / .039 = 1.02	75
	—	1024+	.06 / .037 = 1.62	86		
	256—	512—	.03 / .055 = 0.54	64		
	—	1024+	.13 / .053 = 2.45	95		
	512—	1024+	.10 / .046 = 2.17	93		

O	Compared pitches		Higher pitch longer Diff. / PE diff.	Prob.	Lower pitch longer Diff. / PE diff.	Prob.
					.01 / .015 = 0.66	67
E	128+	256+*b*				
			.08 / .022 = 3.63	99		
	+	512+*b*				
			.11 / .020 = 5.50	100		
	+	1024+*b*				
			.09 / .019 = 4.73	100		
	256+	512+*b*				
			.12 / .017 = 7.0	100		
	+	1024+*b*				
			.03 / .024 = 1.25	80		
	512+	1024+*b*				
					.03 / .015 = 2.00	91
G	128+	256+*b*				
					.06 / .016 = 3.75	99
	+	512+*b*				
					.03 / .016 = 1.87	89
	+	1024+*b*				
					.03 / .015 = 2.00	91
	256+	512+*b*				
			.00 / .014 = 0.00	50	.00 / .014 = 0.00	50
	+	1024+*b*				
			.03 / .016 = 1.87	89		
	512+	1024+*b*				

\+ and — indicate the signs of the constant errors for the pitches in question.
o indicates a constant error of zero.
b indicates that the constant errors for both pitches were reliable.

Tables VII and VIII are examples of tables which were prepared to summarize the effects of pitch on the constant error. In separate tables for each duration and for filled and unfilled intervals these tables present a comparison of each combination

TABLE VIII. *Influence of pitch on constant errors; unfilled intervals; 1.5 sec.*

			Higher pitch longer		Lower pitch longer	
			Diff.		Diff.	
O	Compared pitches		PE diff.	Prob.	PE diff.	Prob.
A	128+	256+*b*			.05 / .047 = 1.06	76
	+	512+*b*	.04 / .058 = 0.68	67		
	+	1024+*b*	.10 / .046 = 2.17	93		
	256+	512+*b*	.09 / .045 = 2.00	91		
	+	1024+*b*	.15 / .029 = 5.17	100		
	512+	1024+*b*	.06 / .044 = 1.36	82		
B	128+	256+*b*	.44 / .069 = 6.37	100		
	+	512+*b*	.17 / .081 = 2.09	92		
	+	1024+*b*	.21 / .075 = 2.80	97		
	256+	512+*b*			.27 / .080 = 3.37	99
	+	1024+*b*			.23 / .075 = 3.06	98
	512+	1024+*b*	.04 / .085 = 0.47	62		
D	128+	256+	.06 / .042 = 1.39	83		
	+	512+	.03 / .041 = 0.73	69		
	+	1024+	.10 / .038 = 2.63	96		

O	Compared pitches		Higher pitch longer Diff. PE diff.	Prob.	Lower pitch longer Diff. PE diff.	Prob.
	256+	512+			.03 / .048 = 0.62	66
	+	1024+*b*	.04 / .045 = 0.88	72		
	512+	1024+	.07 / .043 = 1.62	86		
E	128—	256—*b*	.00 / .022 = 0.00	50	.00 / 0.22 = 0.00	50
	—	512—*b*	.02 / .047 = 0.42	61		
	—	1024—*b*	.01 / .032 = 0.31	58		
	256—	512—*b*	.02 / .044 = 0.45	62		
	—	1024—*b*	.01 / .026 = 0.38	61		
	512—	1024—*b*			.01 / .049 = 0.20	55
F	128+	256+*b*	.04 / .039 = 1.02	75		
	+	512+*b*	.07 / .039 = 1.79	89		
	+	1024+*b*	.03 / .034 = 0.88	72		
	256+	512+*b*	.03 / .046 = 0.65	67		
	+	1024+*b*			.01 / .042 = 0.23	57
	512+	1024+*b*			.04 / .042 = 0.95	74

Legend same as for Table VII.

of pitches for each *O*. The comparison is made by means of the probable error of the difference.[15] For each pair of pitches the difference between the two constant errors is given above the line and the probable error of this difference is given below it with the quotient to the right. If this quotient is equal to or greater than four it is practically certain, from a statistical point of view, that there is a true difference greater than zero between the constant errors for the two pitches in question. Under "Prob." is given the number of chances in one hundred that a true difference greater than zero exists (9, Table XV, 135). These values are grouped under two columns, according to whether the reproduction of the higher pitch or that of the lower pitch is the longer. When the difference is zero the values have been placed in both columns, as there are equal chances of a true difference in either direction. The sign of the constant error for each pitch is given in the columns headed "pitch". A "b" after the compared pitches indicates that the constant errors for both pitches had probabilities of 95 to 100 of being true errors in the direction indicated.

If we take only those differences for which the probabilities of a true difference greater than zero are one hundred as being reliable, we find 14 per cent of the comparisons to be reliable. If those differences having probabilities of 95 to 99 are included, as having a fair degree of reliability, this proportion is increased to 26 per cent. It would seem that the reason for this low proportion of reliable differences might be that on account of small numbers of cases for the separate groups of data many of the constant errors used in the comparisons were unreliable. However, in about half (54 per cent) of the comparisons between different pitches the constant errors for both of the pitches compared were reliable—*i.e.*, the mean constant error for each pitch had a probability of 95 to 100 of being a true error in the direction shown, as indicated by "b" in the tables. If these "reliable" combinations are investigated it is found that 19

[15] The formula for the probable error of the difference between two means is: $PE_{diff.} = \sqrt{PE^2_{M_1} + PE^2_{M_2}}$ (9, 133).

per cent of them have probabilities of 100 of true differences greater than zero, or 35 per cent have probabilities of 95 to 100 of such differences. If only those combinations are considered reliable for which both pitches had constant errors with probabilities of 100, the percentages corresponding to those above are 13 and 27, practically the same as those for the total data. These proportions of reliable differences are not greatly increased over those that were found for the entire body of data, so the failure to find a predominance of reliable differences between the constant errors in a majority of the comparisons between pitches can probably be ascribed only to a very small extent to unreliability of the basic data.

Lacking a majority of reliable differences, if the differences were consistently in one direction for any one *O* or for any one temporal pattern for all *O*s it might be supposed that a tendency exists for a difference in the direction indicated. No such consistency in the trend of the differences can be traced. However by averaging the quotients (the difference divided by the probable error of the difference) for all *O*s for each combination of pitch, duration, and type of interval it was found that in the 28 combinations which were not doubtful (eight were doubtful) the higher pitches tended to be reproduced longer than the lower by a ratio of 18 to 10. That is, in 18 out of 28 combinations both the mean probability of a true difference in this direction —*i.e.*, the longer reproduction of higher pitches—and the number of separate cases in which the difference was in this direction, were greater. If we investigate those combinations of pitches for which the differences found have probabilities of 100 a very similar ratio is found—*i.e.*, 13 of these differences are such that the higher pitch is reproduced the longer, nine are such that the lower pitch is reproduced the longer. This gives only a slight indication in favor of the longer reproduction of higher pitches.

The objective data relative to the influence of pitch on the reproduction of filled and unfilled intervals have yielded the following results: not more than one fourth of all the pitch combinations investigated for all *O*s show reliable differences

greater than zero. In throwing together the data for all *O*s and all durations and types of intervals it was found that a slight majority of the differences indicate that the higher pitch tends to be reproduced longer. This negative result recalls the findings of *Woodrow*, in his investigation of the rôle of pitch in rhythm. Using his method of interference, he found that higher or lower tones had no tendency to end a rhythmic group, as did tones of longer duration, or to begin it, as did more intense tones (**55**).[16]

Inasmuch as no marked regularity appears in the influence of pitch upon the constant error it seems that some other factor than pitch might be responsible for the differences which did appear and which have been established as reliable. Such a possible factor is the pleasantness of the various tones. To find which tones were most pleasant and to find any other subjective factors related to pitch the introspective reports of the *O*s have been examined.

Most of the *O*s found certain tones unpleasant to listen to, especially in the series with unfilled intervals where the tone was sounding constantly except during the silences of the standard and reproduced intervals. Some reports of the various *O*s regarding the pleasantness of the different pitches have been compared with the objective results for these pitches, taken from Tables IV, V and VI, and the corresponding tables of the type of Table VIII. These comparisons were all based on data from the unfilled intervals, for it is doubtful if affective differences were sufficiently marked in series with filled intervals to make the comparison worth while.

For four of the six *O*s for whom comparisons of this type were made, A, C, D, and E, there seems to be some tendency to make the reproductions of the unfilled intervals surrounded with the more unpleasant tones shorter than the others. This trend

[16] In an earlier study *Woodrow* had shown that the tendency of a factor, such as intensity, to begin the rhythmic group was equivalent to the lengthening of the preceding interval, or the tendency to end the group, as in the case of duration, was equivalent to the lengthening of the following interval (**54**, 61–66). It is in the light of this earlier result that Woodrow's results on pitch and our own appear comparable.

is, however, far from being without exception, even for these four *O*s and two others, B and F, show a tendency to make the reproduction of the unpleasantly surrounded unfilled intervals longer. Moreover, although some of the tendencies just indicated are supported by fairly reliable differences, they do not represent the outstanding differences, which must be regarded as unexplained on the basis of unpleasantness. We still lack, therefore a general explanatory principle to account for such outstanding differences as exist, since these do not appear to depend simply either on pitch or on pleasantness. On the whole, there is very little contradiction to the negative result, that pitch is of slight influence upon the reproduction of short temporal intervals.

Constant errors in filled and unfilled intervals. We shall now proceed to a consideration of the central problem, the difference between the reproduction of filled and unfilled intervals of the types used in this experiment. For the basic data the reader is again referred to Tables I to VI. Table IX gives similar data for the unfilled intervals bounded by clicks instead of by tones.

TABLE IX. *Constant errors for unfilled intervals bounded by clicks, division II. 1.5 sec.*

O	No. trials	Mean standard	Mean repro.	Mean CE
A	33	1.43	1.57	+.14 ± .016
C	46	1.48	1.43	—.05 ± .013
D	34	1.51	1.53	+.02 ± .019
E	29	1.48	1.45	—.03 ± .017
G	33	1.48	1.46	—.02 ± .011
H	49	1.50	1.73	+.23 ± .027
I	53	1.48	1.38	—.10 ± .016
J	54	1.47	1.82	+.35 ± .018
K	51	1.47	1.51	+.04 ± .015
L	30	1.47	1.62	+.15 ± .022
M	38	1.49	1.34	—.15 ± .011
N	42	1.50	1.70	+.20 ± .022
O	30	1.46	1.38	—.08 ± .027
P	28	1.41	1.35	—.06 ± .040
Q	36	1.48	1.56	+.08 ± .022

Tables X, XI, and XII are examples of tables which have been prepared to investigate the effect of the type of interval upon the constant error. These are tables of differences, similar in form to Tables VII and VIII.[17] Table XIII gives the classification of the various *O*s according to the direction of the differences in the comparison of filled and unfilled intervals and likewise in the comparisons of each of these types with click-limited intervals.

TABLE X. *Comparison of constant errors in filled and unfilled intervals: 1.5 sec.*

		Filled longer		Unfilled longer	
		Diff.		Diff.	
O	Pitch	PE diff.	Prob.	PE diff.	Prob.
A	128++			.18 / .050 = 3.60	99
	*256+ +*b*	.04 / .028 = 1.42	83		
	512++*b*			.15 / .043 = 3.48	99
	1024++			.19 / .064 = 2.96	98
B	128—+			.24 / .054 = 4.44	100
	256—+*b*			.72 / .049 = 4.69	100
	512 o +			.40 / .067 = 5.97	100
	1024++*b*			.37 / .061 = 6.06	100
C	128— —	.13 / .020 = 6.5	100		
	*256++	.03 / .018 = 1.66	87		

[17] For an explanation of this type of table see explanation of Tables VII and VIII.

		Filled longer Diff.		Unfilled longer Diff.	
O	Pitch	PE diff.	Prob.	PE diff.	Prob.
D	128—+			.04 / .032 = 1.25	80
	256—+			.17 / .056 = 3.03	98
	*256++*b*			.11 / .030 = 3.66	99
	†256++			.11 / .026 = 4.23	100
	512—+			.11 / .047 = 2.34	94
	1024++			.08 / .042 = 1.90	92
E	128+—*b*	.21 / .023 = 9.13	100		
	256+—*b*	.20 / .012 = 16.7	100		
	*256+—*b*	.20 / .020 = 10.0	100		
	†256+—*b*	.19 / .010 = 19.0	100		
	512+—*b*	.27 / .046 = 5.86	100		
	1024+—*b*	.31 / .029 = 10.68	100		
G	*256 o —*b*	.13 / .010 = 13.0	100		
H	*256++*b*	.14 / .032 = 4.4	100		
I	*256—+			.20 / .046 = 4.4	100

		Filled longer		Clicks longer	
		Diff.		Diff.	
O	Pitch	PE diff.	Prob.	PE diff.	Prob.
J	*256++*b*			.25 / .061 = 4.1	100
K	*256++*b*	.02 / .018 = 1.11	77		
L	*256+o	.03 / .019 = 1.57	85		
M	*256+—	.13 / .013 = 10.00	100		
N	*256++*b*			.05 / .028 = 1.8	89
O	*256——*b*	.03 / .038 = 0.78	71		
P	*256++	.26 / .067 = 3.88	100		
Q	*256++*b*			.03 / .032 = 0.93	74

* indicates data from division II.
† indicates totals for divisions I and II.
+, —, and o indicate the signs of the constant errors; that for filled intervals is given first.
b indicates that both the constant errors were reliable.

TABLE XI. *Comparison of constant errors in filled and click-limited intervals: 1.5 sec.*

		Unfilled longer		Clicks longer	
		Diff.		Diff.	
O	Pitch	PE diff.	Prob.	PE diff.	Prob.
A	*256++*b*	.23 / .027 = 8.5	100		
C	*256+—*b*	.11 / .019 = 5.78	100		

		Filled longer		Clicks longer	
		Diff.		Diff.	
O	Pitch	PE diff.	Prob.	PE diff.	Prob.
D	*256++	$\frac{.05}{.026} = 1.92$	90		
E	*256+—	$\frac{.12}{.022} = 5.5$	100		
G	*256 o —	$\frac{.02}{.012} = 1.66$	87		
H	*256++*b*	$\frac{.07}{.034} = 2.05$	92		
I	*256—+*b*			$\frac{.08}{.034} = 2.35$	95
J	*256++*b*			$\frac{.11}{.033} = 3.33$	99
K	*256++*b*	$\frac{.08}{.018} = 4.44$	100		
L	*256+ +			$\frac{.12}{.025} = 4.80$	100
M	*256+—	$\frac{.16}{.014} = 11.42$	100		
N	*256++*b*	$\frac{.00}{.031} = 0.0$	50	$\frac{.00}{.031} = 0.0$	50
O	*256— —*b*			$\frac{.16}{.036} = 4.4$	100
P	*256+—	$\frac{.42}{.052} = 8.07$	100		
Q	*256++*b*	$\frac{.03}{.029} = 1.03$	76		

Legend same as for Table X.

TABLE XII. *Comparison of constant errors in unfilled and click-limited interval 1.5 sec.*

		Unfilled longer		Clicks longer	
		Diff.		Diff.	
O	Pitch	PE diff.	Prob.	PE diff.	Prob.
A	*256++*b*	$\frac{.19}{.024} = 7.9$	100		
C	*256+−	$\frac{.08}{.017} = 4.70$	100		
D	*256++	$\frac{.16}{.030} = 5.3$	100		
E	*256−−			$\frac{.08}{.022} = 3.63$	99
G	*256−−			$\frac{.11}{.013} = 8.46$	100
H	*256++*b*			$\frac{.07}{.036} = 1.94$	91
I	*256+−	$\frac{.12}{.038} = 3.15$	98		
J	*256++*b*	$\frac{.14}{.057} = 2.45$	95		
K	*256++*b*	$\frac{.06}{.021} = 2.85$	97		
L	*256o+			$\frac{.15}{.026} = 5.76$	100
M	*256−−*b*	$\frac{.03}{.014} = 2.14$	92		
N	*256++*b*	$\frac{.05}{.028} = 1.78$	89		
O	*256−−*b*			$\frac{.19}{.040} = 4.75$	100
P	*256+−	$\frac{.16}{.070} = 2.28$	94		
Q	*256++*b*	$\frac{.06}{.033} = 1.81$	89		

Legend same as for Table X.

TABLE XIII. *Classification of Os according to the type of interval reproduced the longer*

Compared types		
f and u	f longer	u longer
	A, C, E, F, G, H, K, L, M, O, P	B, D, I, J, N, Q
f and c	f longer	c longer
	A, C, D, E, G, H, K, M, N, P, Q	I, J, L, O
u and c	u longer	c longer
	A, C, D, I, J, K, M, N, P, Q	E, G, H, L, O

An examination of Tables X and XIII shows that the *O*s fall into two distinct classes—those who tend to reproduce the filled intervals the longer and those who tend to reproduce the silent intervals in a background of tone, *i.e.,* the unfilled intervals, the longer. The relative proportion of the two types is without significance, since the total number of *O*s is so small; it is therefore impossible to predict the true proportion of the two types among individuals in general. The reliabilities are such, however, that we may be statistically certain that two distinct types of individuals in respect to the reproduction of filled and unfilled intervals do exist.[18]

It may appear that the difference in affective quality between the filled and unfilled intervals was responsible for the differences in the constant errors. With the exception of A, all *O*s who ranked the three types of intervals according to pleasantness designated the unfilled series as the least pleasant. *O* said she did not find the unfilled series unpleasant until the very last. The filled and click-limited intervals were not considered unpleasant by any *O*, and the clicks were preferred by all but O and Q.

Now, if the difference in pleasantness was the factor which

[18] For four of the six *O*s who worked with more than one pitch and more than one standard duration, in division I, the direction of the difference found for the comparison of intervals of 256 ~, with a standard of 1.5 sec. duration, is substantiated by the comparisons at other pitches and with the two other standard durations. The exceptions are A and D, and the nature of their deviations is described in the original copy of the study.

determined the difference in length of reproduction in the various types of series, a number of conditions might have obtained. First, those *O*s who made unfilled intervals longer for an unpleasant pitch than for a pleasant one would also have reproduced the unpleasant unfilled intervals longer than the pleasant filled intervals; and, conversely, those who, in the earlier comparison, reproduced the unpleasantly surrounded unfilled intervals shorter than those surrounded with more pleasant pitches, would also have reproduced the unfilled intervals shorter than the filled. Leaving out A, for whom the affective contrast between filled and unfilled intervals did not occur, only three of the other five *O*s, whose reproductions of the unpleasant pitches were described above, had corresponding responses for filled and unfilled intervals.

In the second place, if pleasantness was the differentiating factor between filled and unfilled intervals, in the comparison between filled and click-limited intervals where the affective contrast was a minimum, the differences between constant errors, regardless of direction, would have been less on the average than in the comparisons between filled and unfilled intervals, and between unfilled and click-limited intervals, where the affective contrast was a maximum. This condition was not met in any way, however, for the average differences, regardless of direction, varied only slightly for the three comparisons. They follow: filled compared with unfilled: .111 sec. [19]; filled compared with clicks: .117 sec.; unfilled compared with clicks: .110 sec. If the differences for A are omitted from the three comparisons as not applicable because she did not experience the affective contrast the differences are much the same as above. They are, in the same order: .115 sec., .109 sec., and .104 sec.

A third condition by means of which the hypothesis regarding the effect of pleasantness was tested follows: Since the series with filled and click-limited intervals were both more pleasant than the series with unfilled intervals if the hypothesis regard-

[19] Wherever filled and unfilled intervals are compared with click-limited intervals only the results for 256 ~, 1.5 sec. duration for division II are used, as being strictly comparable with the results for click-limited intervals.

ing pleasantness is correct, an *O* who reproduced the unfilled intervals either longer or shorter than the filled intervals would also have reproduced the unfilled intervals longer or shorter, as the case might have been, than the click-limited intervals. This was found to be true in 67 per cent of the cases, but this majority was equalled on the one hand by the number of *O*s whose filled and unfilled reproductions were correspondingly longer or shorter than their click-limited reproductions, and on the other hand by the number whose click-limited and unfilled reproductions were correspondingly longer or shorter than their filled reproductions. The apparent fulfillment of this condition was therefore without significance.

A final condition is that an *O* for whom the affective contrast did not occur, such as A, and perhaps *O*, would have had smaller differences between the constant errors for filled and unfilled intervals than would those *O*s for whom the affective contrast did occur. In the comparison of filled and unfilled intervals the differences for A and O were actually very small, being .04 and .03 sec., respectively. However, for K, L, N, and Q, the differences were also small—.02, .03, .05, and .03 sec., respectively. On the contrary, in the comparison of unfilled and click-limited intervals, we should expect that A and O would have had smaller differences than the average, but their differences were both .19 sec. larger than for any of the other *O*s.

In summarizing the foregoing review of the evidence relative to the hypothesis that the differences in reproduction of filled and unfilled intervals were due to the difference in affective tone of the two types of series it must first be said that even if the unpleasantness of the unfilled series were to be accepted as an explanatory factor a further explanation would have to be offered for the fact that some *O*s reproduced filled intervals the longer, whereas others reproduced unfilled intervals the longer, when, so far as is known, both groups were affected equally unpleasantly by the unfilled series. An acceptable explanation might be found in personality differences among the *O*s. Although we have no index to such differences among the total group of *O*s, two of

them made remarks which were enlightening. B seemed to have the impression that he was lengthening the unfilled intervals to avoid the return of the unpleasant tone. He was of the type which actually reproduced the unfilled intervals too long and he was more inclined to express discomfort in the unfilled series than was any other *O*. E, on the other hand, once stated that he has a tendency to plunge right into unpleasant things and get them over. He was of the type which shortened the unfilled intervals.

A second possibility is that the individual differences were based on the existence of a cognitive attitude in the case of some *O*s, an affective attitude in the case of others. If this had been true, we should expect that those *O*s who had the cognitive attitude might have been able to respond independently of the affective contrast, even though they recognized its existence, whereas those who had the affective attitude might not have been able to get away from the influence of the affective contrast. The clause in the instruction which warned *O* to "take a strictly objective attitude," was designed to induce the desired "cognitive" attitude. The introspections do not indicate to what extent the various *O*s achieved this attitude, except that it seems highly probable that one *O*, B, did not achieve it, for he spoke frequently of the unpleasant character of the continuous tone. The other *O*s did not mention the unpleasantness except when questioned about it. That it is possible to achieve such a cognitive attitude in a psychological experiment in which affective factors are present has been shown in the study by *Larson* of the Seashore consonance test (18).

A second major hypothesis for the explanation of the influence of the type of interval upon the reproduction and of the individual differences in reproduction is that individuals may have differed in their mode of perception of the unfilled intervals. It is conceivable, for example, that in the series with unfilled intervals, where there was an exact reversal of the physical pattern of tone and silence used in the filled intervals, the *perceived* pattern may not have been a mere reversal. The silence,

when it became the interval, the core of the experience, may have lost the negative quality which characterized it as the continuous background of the intervals, and may have become a positive experience. In the terminology of *Gestalt* psychology, which has become familiar particularly in its application to visual perceptions, silence as "figure" may be a different thing than silence as "ground". The change in character which is referred to may be made clear by means of an illustration given by *Köhler*. The sky, as ordinarily seen, or even when it appears as a bright patch between high houses, has no form.

". . . The houses have forms, but the sky has not. If you wish to see a certain area of the sky as a definite visual form, look at it through a little hole cut into a box which you then put over your head. If the hole is cut like the letter H you will see an area of the sky in the corresponding form as a bright figure on a black ground. And now *this ground* has no visual form" (16, 202).

The qualities of a figure, which has form, as contrasted with an area having the same physical properties, but which is merely ground, are described by *Köhler*. He refers to the rectangle with four diagonal rulings, which may be seen as a slender cross, with diagonal arms, or as a large "Maltese" cross, with thick arms, which extend vertically and horizontally (16, Fig. 9, 197).

"When we see the slender cross, the area of this cross has a character of solidity and coherence; we may even say that this slender cross has the substantiality of a 'thing,' whereas the environment appears as comparatively 'empty' and 'loose.' Exactly the contrary is true when the other cross dominates the field; the large cross becomes 'solid' and 'substantial,' whereas the narrow angles have become 'loose' and 'empty,' like the environment" (16, 219).

Just as the sky in *Köhler's* illustration took on a positive quality when it was seen as figure, against the dark ground of the box, and became a form in the same sense that the dark houses had been forms when viewed against the bright sky, so we are conjecturing that in the present experiment the silence may have taken on a positive quality, similar to that of the filled intervals, when it appeared as an interval, rather than as the homogeneous background for intervals. The perception of a "positive silence" has been noted before. *Smith* and *Barlett,* working with sounds of weak intensity, found it. They say:

"One of our observers frequently noticed an effect which could be described only in the terms 'positive silence,' and which was very clearly distinguished from that accompanying the mere absence of sound" (**41**, 145).

Titchener, likewise, in discussing the sensory character of black, has a good deal to say about the perception of silence. He reviews the sensory factors which may carry the meaning of silence, then he says:

"But when the silence becomes significant, and we enquire for the conscious processes which carry the meaning of a significant silence, then we have passed beyond perception to the levels of association and attitude and acquired interest. Unfortunately, the group of experiences to which this particular mode of apprehension belongs has not yet been brought under experimental control" (**48**, 116).

He later takes up *Meumann's* discussion of the rôle of the rest in rhythm. He considers *Meumann's* remarks inadequate, but he says:

"It illustrates, however, what I take to be indisputable, the complex and positive character, psychologically considered, of the rest-experience" (**48**, 118).

In order to determine whether or not the silent intervals did take on a positive quality in this experiment, the *O*s were asked to describe the character of the tone and silence in the different types of intervals and to tell whether the silence became positive in the unfilled intervals. Clear answers were obtained from only eight of the *O*s. Six of these—A, C, G, K, L, and O—said that the silence did become positive in the unfilled intervals. A, for example, said that the silence was "decidedly positive." The experience of silence in the series with unfilled intervals was not a mere reversal of that in the filled. "They were separate entities which I did not relate to each other." G stated that the filled and unfilled intervals reduced to the same thing, due to the positive quality of the silence in the unfilled intervals. O characterized the silence in the unfilled intervals as "heavier" than that in the filled series. On the contrary, two *O*s, E and N, did not have this experience of positive silence. E said emphatically that the silence was never positive for him, and that the empty intervals were always characterized by a feeling of suspense. N said that the unfilled intervals were "empty, hollow."

Apparently the analogy with the reversal of figure and ground in visual perception holds in the case of certain *O*s and does not hold in the case of others.[20]

Between the first six and the last two of these *O*s there is certainly a difference in perception. Do the objective data show the influence of this difference? We should expect that the *O*s who agree in perceiving the unfilled intervals as negative or positive in quality will agree in their objective results. In the first place, do the members of each group agree in respect to the direction of the differences between the reproduction of filled and unfilled intervals? E and N, who perceived the unfilled intervals as negative, do agree in making a positive error for filled intervals, but E reproduced the unfilled intervals shorter than the filled, whereas N reproduced the unfilled intervals the longer. The difference for E is large and highly reliable, for N it is small and has a probability of only 89.[21] The six *O*s who agreed in perceiving the unfilled intervals as positive all reproduced the unfilled intervals shorter. It appears that the contrast in manner of perceiving the unfilled intervals does not necessarily bring about a contrast in the direction of the difference between the reproductions of filled and unfilled intervals, for E, one of the two who perceived the negative quality in the unfilled intervals and who had the larger and more reliable difference between the reproduction of filled and unfilled intervals, reproduced the unfilled intervals shorter than the filled, just as did the six *O*s who perceived the positive quality in the unfilled intervals. Although the contrast in perception may not be accompanied by a contrast in the *direction* of the difference between the reproductions of the two types of intervals, it may,

[20] The fact that certain *O*s heard a positive quality in the unfilled interval can not be attributed to the fact that some *O*s sometimes heard a very faint tone in the unfilled interval, which was believed by them to be of a subjective nature. In the first place, this faint tone was heard by E, who did not perceive the positive quality in the unfilled intervals, as well as by some of the *O*s who did have that perception. In the second place, none of the *O*s seemed to refer the positive quality to the faint tone, and one specifically stated, quite of his own accord, that the positive quality was somehing "superimposed upon the slight subjective tone".

[21] See Tables II, V, and X.

however, be responsible for a contrast in the *extent* of the differences between the reproductions. The following paragraphs will show that this appears to be the case.

The second question is, then: Do the two *O*s who have the negative perception of the unfilled intervals have greater differences in the filled-unfilled comparison than the six who have the positive type of perception? E conforms to the expectation that this question should be answered in the affirmative, N does not. The average difference for the six who experienced the positive quality is .046 sec. For E the difference is .20 sec., but for N it is the same as the average of the other group, .05 sec. The difference for E is highly reliable, however, that for N is not.

A third question, which we may expect to be answered in the affirmative if the perception of an interval as a positive thing is the important factor in determining the reproduction of that interval, is as follows: Do the six *O*s who perceive the unfilled intervals as positive show greater differences between filled and click-limited intervals than between filled and unfilled intervals? It is assumed that the click-limited intervals present a configuration which is different from that of the filled and unfilled intervals, and it may be supposed that if the perceived patterns are not similar the reproductions will be different. This expectation is fulfilled, both by the average differences in the two comparisons and by each of the six *O*s, with the exception of G. The average differences are .046 and .120 sec. for the comparisons of filled with unfilled, and filled with click-limited intervals, respectively. The validity of this contrast is emphasized by the fact that it does not hold for the *O*s of the opposing type, E and N.

A final question arises from the expectation that, since for these six *O*s the filled and unfilled intervals seem to be so much alike, in the comparison between unfilled and click-limited intervals we shall find that the reproductions of unfilled intervals show the same relation to those of click-limited intervals which the reproductions of filled intervals showed to them in the comparison between filled and click-limited intervals. That is, if the

filled intervals were reproduced longer than the click-limited it may be expected that the unfilled will likewise be reproduced longer, or *vice versa.* This expectation is fulfilled in five of the six cases. A, C, and K reproduced both filled and unfilled intervals longer than click-limited intervals, and L and O reproduced both filled and unfilled intervals shorter than click-limited intervals. Only in the case of G does the direction of the difference vary in the two comparisons.

In concluding the foregoing discussion of the influence of the contrasting tendencies to perceive the unfilled intervals as positive or negative in character, we may say that although an explanation is still lacking for the fact that some *O*s reproduce filled intervals longer than unfilled and that others reproduce unfilled intervals longer than filled, yet there is strong evidence for the belief that the existence and the extent, if not the direction, of a decided and reliable difference between the reproductions of filled and unfilled intervals may be determined by the presence or absence of a positive character given to the silence of the unfilled interval. This positive quality may characterize an unfilled interval which is bounded by a continuous tone, and it is assumed that it is this quality which may cause the differences between the reproductions of filled and unfilled intervals to be very slight, and which may cause the reproductions of unfilled intervals of this type to differ from those of click-limited unfilled intervals in the same direction in which filled intervals differ from the latter type. The effect of failure to endow the unfilled intervals with this positive quality is probably in the direction of a greater difference in the constant errors for filled and unfilled intervals. Possibly when the interval does not take on the positive character other influences which this study was not adapted to bring out may have a greater effect upon the reproduction. It may be recalled here that Curtis found more secondary criteria in empty—*i.e.,* click-limited—than in filled intervals.

Interpretation of the constant error. A final question which has a place in the discussion of the constant errors obtained in this study is that of their interpretation in terms of over- and

underestimation. In the presentation of the results we have avoided the question by referring merely to the positive or negative character of the errors, or to the length of the reproductions. It appears, however, that it should be possible to speak of the results in terms of over- and underestimation, and that we ought to determine the proper interpretation of the constant errors.

The data themselves offer a source of evidence for the point of view that a positive error means underestimation of the reproduced interval and a negative error its overestimation. This evidence is found in the *O*s' own judgments regarding the direction of their errors. It was at first intended to have the *O*s make a judgment of the direction of the error following each trial, but this plan was abandoned for fear of suggesting inaccuracy. In division I of our series of experiments the *O*s who took part were merely asked to record by means of numbers the degree of their certainty regarding their accuracy. Three *O*s, however, often spontaneously recorded what they believed to be the direction of their error in trials where they did not record perfect certainty. These *O*s were A, B, and E.

When an *O* judges his error to have been in the direction in which it actually was, he gives no index to any illusion which may exist in his estimation of the durations. But when he makes an error in judgment we may have a key to his illusion. If, for example, he shows a strong tendency to judge as too long reproductions which are really too short—*i.e.*, which have a negative error—this may be regarded as an indication that he overestimates his reproductions. There are four criteria which will aid in determining whether or not an *O* has such a tendency to over- or underestimation, as the case may be. Let overestimation be taken as an example. It may be supposed that an *O* has a tendency to overestimation if the following four conditions exist: First, if he makes most of his wrong judgments[22] in trials which have negative errors; second, if the per cent of his wrong judg-

[22] A "wrong judgment" will here mean one in which a reproduction was judged as too long when it was actually too short or just right—*i.e.*, had a negative or zero error—or in which a reproduction was judged as too short, when it was actually too long or just right—*i.e.*, had a positive or zero error.

ments which are in trials with negative errors is greater than the per cent of all judgments, right and wrong, which are in trials with negative errors; third, if the per cent of wrong judgments which are in trials with negative errors is greater than the per cent of right judgments which are on trials with negative errors; and fourth, if a greater per cent of all the trials with negative errors are judged wrongly than are judged rightly. If these conditions are fulfilled it may then be supposed that *O* has a tendency to overestimate—or, if "positive errors" are substituted for "negative errors" in the above outline, it may be supposed that he has a tendency to underestimate.

When the data for the three *O*s, A, B, and E, who gave judgments of the direction of their errors, were investigated in the light of the above criteria it was found that A fulfills all four of the criteria, showing a strong tendency to be mistaken in judgments of trials with positive errors, in the case of both filled and unfilled intervals. It may therefore be concluded that A has a tendency toward underestimation of the second interval. In Tables I to VI it is found that A's actual errors are nearly all positive, with the exception of those for intervals with a standard duration of 2.5 sec. A re-investigation of the judgments shows that in the case of intervals of this duration a much larger proportion of negative errors was misjudged than in the case of the other durations. We have here, then, indications that a tendency to underestimation is accompanied by a tendency to make positive errors.

B makes wrong judgments on negative errors, for filled intervals, fulfilling all but the fourth criterion. The actual errors are predominantly negative, so that we have evidence for overestimation, associated with negative errors. With unfilled intervals the case is just the opposite, as the wrong judgments are on positive errors, and the actual errors are predominantly positive. There is evidence for underestimation associated with positive errors, although only the first two criteria are met.

E fulfills the first three criteria for both filled and unfilled intervals. For filled intervals he is mistaken in the judgment

of positive errors, and the actual errors are predominantly positive, an indication of underestimation connected with positive errors. For unfilled intervals there is similar evidence for overestimation associated with negative errors.

The data just reviewed indicate that in the case of the three *O*s in question overestimation, as determined by a tendency to judge reproductions long when they are really too short, is in general associated with a majority of negative errors of reproduction, and *vice versa,* that underestimation, as determined by a tendency to judge reproductions short when they are really too long, is in general associated with a majority of positive errors of reproduction. This is the only evidence which the data from the present study offer for the interpretation of the errors of reproduction. Lacking evidence to the contrary, we shall conclude tentatively, then, that positive errors of reproduction mean underestimation of the reproduced interval, and that negative errors mean its overestimation.

Variability of reproduction. The constant errors, to the discussion of which the preceding sections have been devoted, are only averages showing more or less constant tendencies to over- and underestimation. The measure chosen to indicate the variability in these tendencies is the standard deviation, which indicates the regularity with which *O* approached his average constant error.[23]

Tables XIV, XV, and XVI give the standard deviations for filled, and click-limited intervals for standard durations of 0.5, 1.5, and 2.5 sec., respectively. For each type of interval the

[23] The measure of variability used was based upon the distribution of errors rather than upon the distribution of reproductions, although the latter is the traditional practice. This was done on account of the varying standard. With a constant standard the variability of the distribution of reproductions would of course be equal to that of the distribution of errors. The variation of the standard will automatically increase the variability of the distribution of reproductions, aside from any mental effect due to the lack of uniformity of the standard. The variability of the distribution of errors is more purely due to mental causes than that of the distribution of reproductions. It is for this reason that the measure of variability used was based upon the distribution of errors. The standard deviation was chosen instead of the more usual average error or mean deviation because it is a more reliable measure.

deviation is given first in seconds and then in per cent of the standard duration.

TABLE XIV. *Standard deviations for filled and unfilled intervals. 0.5 sec.*

		Filled		Unfilled	
O	Pitch	Sec.	Per cent	Sec.	Per cent
A	128	.002	0.3	.024	4.8
	256	.067	12.6	.040	7.8
	512	.034	5.6	.055	10.3
	1024	.024	4.2	.078	14.4
B	128			.220	40.7
	256			.394	75.7
	512			.464	84.3
	1024			.178	33.5
C	128	.057	12.6	.041	7.1
	256	.059	13.1		
	512	.085	18.8		
	1024	.002	0.4		
D	128	.091	20.2	.137	23.6
	256	.184	40.8	.102	17.8
	512	.137	31.8	.137	24.0
	1024	.098	22.2	.178	30.1
E	128			.064	12.0
	256			.056	10.3
	512			.077	13.5
	1024			.060	10.5
F	128			.068	13.3
	256			.085	16.3
	512			.076	14.6
	1024			.100	18.5

TABLE XV. *Standard deviations for filled, unfilled, and click-limited intervals. 1.5 sec.*

		Filled		Unfilled		Click-limited	
O	Pitch	Sec.	Per cent	Sec.	Per cent	Sec.	Per cent
A	128	.102	6.2	.189	12.7		
	256			.101	6.5		
	* 256	.212	14.2	.177	11.4		
	† 256			.178	11.4		
	512	.034	2.0	.208	13.5		
	1024	.207	12.9	.075	4.8		
	*					.143	10.0
B	128	.166	11.7	.356	22.5		
	256	.128	8.9	.481	31.2		
	512	.161	11.4	.393	25.5		
	1024	.168	11.9	.342	22.2		
C	128	.111	7.7	.050	3.2		
	256	.109	7.5				
	*256	.203	13.7	.165	10.5		

		Filled		Unfilled		Click-limited	
O	Pitch	Sec.	Per cent	Sec.	Per cent	Sec.	Per cent
	†256	.226	15.3				
	512	.099	6.8				
	1024	.166	11.5				
	*					.135	9.1
D	128	.147	10.0	.166	10.5		
	256	.200	13.8	.197	12.5		
	* 256	.172	11.6	.224	14.3		
	† 256	.188	12.7	.220	14.1		
	512	.170	11.7	.197	12.6		
	1024	.175	12.1	.197	12.4		
	*					.169	11.1
E	128	.101	7.1	.124	7.8		
	256	.107	11.9	.117	7.4		
	* 256	.118	7.9	.123	7.9		
	† 256	.112	7.7	.122	7.8		
	512	.126	8.8	.272	17.2		
	1024	.115	8.0	.155	9.9		
	*					.143	9.6
F	128			.106	6.9		
	256			.184	11.7		
	512			.201	12.8		
	1024			.163	10.3		
G	128	.091	6.3				
	256	.081	5.6				
	* 256	.095	6.3	.117	7.5		
	† 256	.107	7.2				
	512	.096	6.6				
	1024	.085	5.9				
	*					.102	6.8
H	* 256	.223	14.9	.221	13.8		
	*					.284	18.9
I	* 256	.284	19.4	.328	21.1		
	*					.176	11.8
J	* 256	.263	18.0	.495	29.6		
	*					.202	13.7
K	* 256	.151	10.2	.223	14.1		
	*					.162	11.0
L	* 256	.183	12.5	.206	13.2		
	*					.179	12.1
M	* 256	.133	8.9	.150	9.3		
	*					.106	7.1
N	* 256	.176	11.8	.162	10.0		
	*					.212	14.1
O	* 256	.222	15.2	.274	16.8		
	*					.221	15.1
P	* 256	.315	21.7	.333	21.3		
	*					.320	22.6
Q	* 256	.193	12.9	.251	15.9		
	*					.202	13.6

Legend same as in Table IV.

TABLE XVI. *Standard deviations for filled and unfilled intervals. 2.5 sec.*

		Filled		Unfilled	
O	Pitch	Sec.	Per cent	Sec.	Per cent
A	128	.254	9.4	.275	11.5
	256	.182	6.9	.134	5.3
	512	.243	9.8	.204	8.1
	1024	.213	8.0	.292	11.4
B	128			.623	24.1
	256			.577	22.3
	512			.596	23.6
	1024			.474	18.8
C	128	.100	4.1	.160	6.4
	256	.205	8.4		
	512	.138	5.6		
	1024	.147	6.0		
D	128	.174	7.0	.337	13.3
	256	.254	10.5	.281	11.1
	512	.191	7.9	.291	11.4
	1024	.256	10.5	.292	11.4
E	128			.147	5.8
	256			.296	11.5
	512			.312	12.0
	1024			.171	6.6
F	128			.127	5.0
	256			.233	9.0
	512			.224	8.7
	1024			.251	9.6

The only case in which there is a marked contrast in the variability for filled and unfilled intervals is in the case of B, in Table XV. B was much more variable in his reproduction of filled than of unfilled intervals, and this was true for the durations 0.5 and 2.5 sec., as well as for 1.5 sec. In the case of A there is a good deal of difference between filled and unfilled intervals in the variability of reproduction of separate pitches, especially for the durations 0.5 and 1.5 sec., but the difference is not always in the same direction, so that on the average the variability is much the same for the two types of intervals, and for all pitches. The variability in the reproduction of click-limited intervals is also in general little different from that of the other two types, with the exception of the data for H, I, and J, as shown on the second page of Table XV. Of these three *O*s, H is the only one for whom the variability is increased in the click-limited intervals. The differences between the standard devi-

ations for the three types of intervals appear to be on the whole less marked than the differences in constant errors.

By consulting the standard deviations given for each type of interval in terms of per cent it will be found that in the majority of cases the variability of the reproductions does not exceed that reported by *Wallin* to have been heard as "medium" rhythm by his *O*s. The per cent given by *Wallin* is 12.0 (51, 107).[24] The *O*s who greatly exceed this per cent are D, for the standard duration of 0.5 sec., Table XIV; B, for unfilled intervals; and H, I, J, O, and P for intervals of 1.5 sec., Table XV. None of these *O*s were among those classed as "musical". It may be pointed out here that for purposes of musical effect the variability is much more important than the direction or amount of the constant error, for if a constant error is made consistently the temporal relations of the musical arrangement will not be destroyed.

The scores from the Seashore test for the sense of time. It is now possible to make a comparison of the accuracy shown by the *O*s in the Seashore test for the sense of time and in the reproductions of the three types of intervals.

In order to summarize the relationship between high scores on the test and high accuracy—*i.e.*, low variability—in reproduction, the scores for the 15 *O*s were correlated by the method of rank differences with the standard errors for reproductions of filled, unfilled, and click-limited intervals, taken from Table XV. The three *rhos* found by this method were converted into *r*s by means of the table given by *Garrett* (9, 192). The results were as follows, for test scores correlated with standard errors of filled, unfilled, and click-limited intervals, respectively: $+.879\pm.04$, $+.803\pm.06$, and $+.832\pm.05$. The results are not greatly different for the three types of intervals, and the coefficients are high enough to indicate that an individual making a high score on the test for sense of time will tend to have a low degree of variability in the reproduction of temporal intervals, whether

[24] It should be remembered that the standard deviation is equal to 1.2533 times the mean deviation (9, 85), so that in comparing these per cents with those of *Wallin* the former should be decreased by about one-fifth.

they are filled, unfilled surrounded by tones, or limited by clicks. Of course the cases are too few and the method of rank differences is too unreliable to enable predictions to be made from the test scores to the variability of production of intervals, but it would appear that these results present an interesting lead for further investigation. With a sufficiently large number of cases the Pearson product moment method of correlation could be used and regression equations could be set up, from which the probable variability of individuals in the production of temporal intervals might be predicted from the Seashore test scores. The meaning of the different degrees of variability might then be checked by means of further investigation along the lines of the study by *Wallin*.

V. Summary of Conclusions

The purpose of this study has been to investigate the differences in reproduction of short temporal intervals when these intervals are presented in different physical patterns. The particular patterns used were designed to parallel more closely the actual musical situation than do the empty click-limited intervals of the Seashore test for the sense of time. The intervals were presented in three forms: filled, consisting of tones of short duration; unfilled, consisting of gaps in a continuously sounding tone; and click-limited, consisting of short intervals bounded by clicks, similar to the pattern used in the Seashore test, and used here for control purposes only. In order still further to parallel the musical situation the method of reproduction was used, rather than a judgment method.

The greater part of the data was obtained from standard intervals of 1.5 sec. duration, filled or surrounded by tones of 256 ~, in addition to the click-limited intervals of the same duration. Supplementary data were obtained from standard intervals of 0.5 and 2.5 sec. duration, and from intervals of all three durations filled or surrounded by tones of 128, 512, and 1024 ~. A secondary problem of the study was the effect of the pitch of the tonal filling or background upon the reproduction of the filled and unfilled intervals. Further objectives have been the interpre-

tation of the positive and negative errors in terms of over- and underestimation, and the comparison of the results of the experiment with those of the Seashore test for the sense of time.

An examination of the constant errors of reproduction shows that in respect to the differences in reproduction between filled and unfilled intervals there are two distinct types of *O*s. Some *O*s have positive and others negative constant errors for filled or for unfilled intervals, and some reproduce the filled intervals longer, others reproduce the unfilled longer. The most significant result which has come out of the attempt to compare the filled and unfilled intervals has been the discovery that some of the *O*s perceived the unfilled intervals as positive entities, not unlike the filled intervals—that there was, in short, a manner of reversal of figure and ground, in which the silence became the figure when it was the interval to be reproduced. Some of the *O*s did not experience this reversal, and there is evidence that the existence of a marked difference between the constant errors of reproduction for the filled and unfilled intervals depends upon this lack of reversal. However, this contrast in perception does not explain the individual variation in the direction of the differences between the errors for filled and unfilled intervals, for certain *O*s of both types showed differences in the same direction. The existence of a difference in pleasantness in the filled and unfilled intervals likewise failed to explain the individual differences in constant errors, and was a less satisfactory basis for the explanation of the difference in extent of contrast between the reproductions of filled and unfilled intervals than was the difference in mode of perception of the unfilled intervals. Individual differences must probably be explained by differences in the secondary criteria used in the estimation of durations, and by differences in attitude.

The results relating to the effect of pitch upon the reproduction were largely negative. Its slight influence in the case of some individuals may possibly be explained on the basis of a difference in pleasantness between the tones, yet the largest and most reliable differences between pitches can not be explained in this

manner. Furthermore, the effect of the contrast in pleasantness is not the same in the case of all individuals. There seems to be a slight tendency to reproduce the intervals filled or surrounded by a higher pitch longer than those filled or surrounded by lower pitches.

In attempting to establish a principle for the interpretation of positive and negative errors of reproduction in terms of over- and underestimation the available evidence points to the interpretation of positive errors as indicative of underestimation of the reproduced interval, and of negative errors as indicative of overestimation of the reproduced interval.

The variability of the constant errors differs little for the three types of intervals. This was shown by means of the standard deviations of the distributions of constant errors. *O*s who have been classed as "musical" all appear to have a variability which does not exceed a certain limit of undesirability, as defined by *Wallin*. The score from the Seashore test for the sense of time tend, furthermore, to agree with the degree of variability in the reproduction of intervals, regardless of the type of interval. These facts have suggested the possibility of basing predictions as to the probable variability of individuals in the production of temporal intervals upon the Seashore test scores, by means of regression equations derived from correlations of the test scores with measures of variability of reproduction, such as the standard deviations of the present study.

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EXPERIMENTAL STUDIES IN THE USE OF THE TONOSCOPE

by

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I. INTRODUCTION [1]

The present article is intended as a contribution toward the standardization of procedure in tests of vocal control of pitch, using the Seashore tonoscope as an objective criterion of the accuracy of singing. *Seashore* (23) has recently published a manual of directions for the use of the tonoscope, and this paper may be considered primarily as a technical supplement to the manual.

The treatment includes: (1) a technical description of the new features of Model VI of the tonoscope, (2) critical and experimental studies in the technique of testing pitch control of the voice, and (3) the construction of a set of tests for the measurement of this ability. In the progressive development of the analysis of the factors involved, *Seashore* (22) has recognized the following basic abilities in vocal control of pitch: reproduction of a tone, singing of musical intervals, and voluntary control over fine shadings of pitch. While the studies in the present work refer most directly to measurements on these three fundamental processes, it is assumed that the principles deduced are applicable in general to the great variety of modifications of which the tests are capable, according to the particular purpose of the experimenter. The principles will apply also in general

[1] Grateful acknowledgment is made to Professor C. E. Seashore for critical guidance throughout the progress of these studies. The work was carried on during the writer's tenure of a fellowship in the psychology of music, endowed by Mr. George A. Eastman.

to other forms of musical performance where the individual has control over the pitch of his instrument.[2]

II. Apparatus

New features of the Iowa tonoscope, model VI.[3] Three models of the tonoscope have been described in the literature, the original design (19), the standard laboratory instrument (20), and the portable phonograph model (22). Model VI, designed to take the place of the first portable model, incorporates several new features which are described in this section.

A. Reading units in fractions of a tone. All previous models of the tonoscope have been graduated in ~. It was decided to use fractions of a whole tone in the tempered scale as units in the new model chiefly because of the greater ease in the use and interpretation of results, since this division makes scale readings directly comparable in all octaves without further calculation. The scale reads directly to one-tenth of a tone, but it is possible, with steady tones, to read in much finer units by the method of interpolation described by *Seashore* (19). For example reading in twentieths of a tone can be done quite as easily as reading in tenths by noting points where two adjacent rows move with equal speed in opposite directions.

Although frequency values for any scale may be read on the tonoscope, the frequencies were calculated originally from the values of the tempered scale. This is essentially a logarithmic scale, in which the octave represents a ratio of 1:2, and in which the successive semitones bear a ratio to each other equal to the twelfth root of two, or 1.05946. In order to find the frequency of each equal semitone it is necessary merely to multiply the frequency of the note below it by this factor. Thus, starting with C_1 equal[4] to 129.33 ~, the frequency of C♯ will be the product of this value and 1.05946, or 137.019.

[2] The historical aspects of the problem are not treated separately in this paper chiefly because such a large proportion of the work quoted was of incidental rather than central interest to the original investigators; a complete discussion of their problems would often lead away from the present interest. The plan has been adopted, therefore, of quoting only the relevant experimental material in direct connection with the specific problem. The work in the field up to 1914 has been summarized by *Miles* (16). *Brennan* (4) has given a recent summary of the work in the Iowa laboratory.

[3] Manufactured by the C. E. Stoelting Co., 424 N. Homan Ave., Chicago, Ill.

[4] Middle C is designated as C; octaves above as C^1, C^2, *etc.*, below as C_1, C_2, *etc.*

If one desires to work in logarithms entirely the scale may be constructed by adding consecutively log. 1.05946, which is .025086, translating back to the actual frequencies by the aid of a logarithmic table. A scale of 60 steps, such as was required in this case, can be constructed by adding consecutively 1/5 of .025086, and finding the anti-log., or by multiplying consecutively by the 60th root of two, or 1.0116. In the derivation of the scale both methods were used.

Since the phonograph motor is designed to run at a speed of approximately 78 r.p.m., however, the actual number of dots in each row of the tonoscope drum were reduced to the base, 100, instead of the base, 129.33 which is C_1 in International Pitch. This was done by calculating the values for each tenth of a tone first from the base 129.33, and then multiplying these values by the constant factor, 100/129.33. This requires that the tonoscope be run at a speed of 77.6 r.p.m. in order to yield a scale of frequencies which is just at International Pitch. Changing the speed from this value will of course, not affect the relative values of the frequencies.

It was necessary in order to avoid a disagreeable flicker in stroboscopic perception, to make certain deviations from this set of theoretically exact values in order to obtain a whole number of spaces in each row of the scale, and since no logarithmic scale can have an integral number of vibrations in every step, some error is inevitable in any such procedure, no matter how large the numbers are made. The simple rule was adopted of taking the whole number nearest to the theoretical value for each tenth of a tone.

Table I gives in column 1 the values for each tenth of a tone in the tempered scale in International Pitch, and in column 2, these values multiplied by 100/129.33. In column 3 the integral number nearest to the theoretical value is given. In columns 4 and 5, the error in ~ and parts of a tone are given. The errors in ~ are correct only when the tonoscope is run at the specified speed. They must be multiplied by 2 for each octave above the fundamental octave of the tonoscope (C_1 to C). The errors in parts of a tone are calculated by dividing the values in ~ by the number of ~ in a whole tone at each level. These errors will be constant for all octaves.

TABLE I. *Frequencies of parts of a tone in the temporal scale at International pitch, frequencies reduced to the values required for the tonoscope scale, and errors introduced by taking nearest integers*

Note	International Pitch	× 100/129.33	Nearest integer	Error in ~	Error in parts of a tone
	126.37	97.72	98	*—.36	—.02
	127.84	98.85	99	—.20	—.01
C_1	129.33	100.00	100	0.00	0.00
	130.83	101.16	101	—.21	—.01
	132.35	102.33	102	—.43	—.03
	133.89	103.52	104	.62	.04
	135.44	104.72	105	.36	.02
C♯	137.02	105.94	106	.08	.01
	138.60	107.17	107	—.22	—.01
	140.20	108.41	108	—.53	—.03
	141.82	109.67	110	.43	.03
	143.47	110.94	111	.08	.01
D	145.16	112.24	112	—.31	—.02
	146.84	113.53	114	.61	.04
	148.54	114.84	115	.21	.01
	150.26	116.18	116	—.23	—.01
	152.00	117.52	118	.62	.04
D♯	153.80	118.92	119	.10	.01
	155.58	120.30	120	—.39	—.02
	157.38	121.69	122	.40	.02
	159.31	123.11	123	—.14	—.01
	161.06	124.53	125	.61	.04
E	162.94	125.98	126	.03	0.00
	164.83	127.44	127	—.57	—.03
	166.74	128.92	129	.10	.01
	168.67	130.41	130	—.53	—.03
	170.63	131.93	132	.09	0.00
F	172.63	133.48	133	—.62	—.03
	174.63	135.03	135	—.04	0.00
	176.66	136.59	137	.53	.03
	178.71	138.18	138	—.23	—.01
	180.78	139.78	140	.28	.01
F♯	182.89	141.41	141	—.53	—.03
	185.01	143.05	143	—.06	0.00
	187.16	144.71	145	.38	.02
	189.33	146.39	146	—.50	—.02
	191.53	148.09	148	—.12	—.01
G	193.77	149.82	150	.23	.01
	196.02	151.55	152	.58	.03
	198.29	153.31	153	—.40	—.02
	200.59	155.09	155	—.11	—.01
	202.92	156.88	157	.16	.01
G♯	205.29	158.73	159	.35	.02
	207.67	160.57	161	.56	.02
	210.08	162.43	162	—.56	—.02
	212.52	164.32	164	—.41	—.02
	214.99	166.22	166	—.28	—.01
A	217.50	168.17	168	—.22	—.01
	220.02	170.12	170	—.16	—.01
	222.57	172.09	172	—.12	0.00
	225.15	174.09	174	—.12	0.00
	227.76	176.11	176	—.14	—.01
A♯	230.43	178.17	178	—.22	—.01
	233.10	180.24	180	—.31	—.01
	235.80	182.33	182	—.43	—.01
	238.54	184.44	184	—.57	—.02
	241.31	186.58	187	.54	.02
B	244.14	188.77	189	.30	.01
	246.97	190.95	191	.06	0.00
	249.82	193.17	193	—.22	—.01
	252.72	195.41	195	—.53	—.02
	255.65	197.67	198	.43	.01
C	258.66	200.00	200	0.00	0.00
	261.66	202.32	202	.42	.01
	264.70	204.66	205	—.43	—.01

* The negative sign indicates the error to be in the direction of flatting.

B. The stenciled drum. By a special process the pattern of dots is stenciled on the drum.[5] In order to facilitate the reading the notes of the chromatic scale are printed in somewhat larger dots than the tenths of a tone. In order further to increase the accuracy of reading the " framing effect ", developed by *Seashore* (19) for the standard laboratory model has been adopted. The rows of dots extending from C to F ♯ cover the whole face of the drum, alternating with the rows of dots extending from F ♯ (repeated) to C. The scale is extended two tenths of a tone beyond the octave at each end.

C. The speed check. A speed checking device which depends upon 60 cycle A.C. is included in the complete apparatus. A neon lamp which is connected directly to the 60 cycle current illuminates a row containing 93 dots at the top of the drum. When this row is stationary and the current is of exactly 60 cycles frequency, the pitch of the fundamental tone is 129.03, this being the nearest approximation to International Pitch possible with this arrangement. The tonoscope may be adjusted to any other fundamental frequency, such as the orchestral pitch of A 440, by sounding a tuning fork of known frequency into the transmitter and adjusting the speed control dial until the proper row is stationary.

D. The lighting system. A fundamental difficulty of long standing in the use of the tonoscope in a practical way has been the lack of a convenient and sensitive source of interruption of light. During the course of this investigation a number of devices were tried. These were the manometric flame, in which the vibrations of the voice were transmitted either directly or electrically to the capsule, the mercury arc light, the phonelescope, as described by *Metfessel* (12), and an adaptation of the oscillating mirror, in which the mirror was attached directly to the vibrating unit of a radio loud speaker. The manometric flame gave a clear pattern, but was very inconvenient to use, blowing out very easily, and forcing the singer to hold the mouthpiece so close to his mouth as to interfere seriously with tonal produc-

[5] Devised by Mr. C. E. Stoelting.

tion. The mercury arc light gave a very poor pattern of dots, and was very insensitive, unless excessive voltage was put on the microphone, causing rapid deterioration. The oscillating mirror devices gave insufficient light for easy reading, and were rather delicate and difficult to keep in adjustment.

A unit [6] consisting of a neon lamp and a two-stage vacuum tube amplifier was finally adopted. The neon lamp gives, when in operation, a soft orange-colored glow which adequately illuminates the whole area of the drum when three small lamps are used. The room need be only partially darkened for satisfactory operation of the system, a circumstance in which the new source of light is far superior to all previous devices. The time of flash of the neon lamp is very short, the dots being as a consequence very sharp and distinct.

During the course of attempts to make the response of the apparatus more equal under all conditions it was discovered that the addition of a horn of the exponential type, directly attached to the microphone, was of considerable value. The sensitivity can be changed by a rheostat control on the panel.

With the above arrangements adjustments can be easily made for all changes in vowel or differences in the energy output of voices. The sensitiveness of the system is approximately equal for the vowels a, o, and u, but somewhat lower for i and e [7]. The adjustment from vowel to vowel is, however, merely a matter of changing the position of the singer slightly before the horn, or of varying the control of sensitivity. The clearness of the pattern of dots is best when the singer sings with a rather weak intensity of voice, overtones occasionally appearing in the pattern when tones are sung too loudly. The practical advantage of this change in the lighting system is very great in that the singer is no longer hampered in vocal production in any way by the apparatus, but can concentrate in a normal way on tonal production and control of pitch.

[6] Designed and built by Dr. C. F. Lorenz of East Orange, New Jersey, to whom grateful acknowledgment is hereby made.

[7] Throughout the present research the symbols of the International phonetic alphabet will be used to designate the vowel qualities.

The distinctness of the pattern is somewhat reduced at frequencies above the first octave. In the first octave the dots are very black. In all succeeding octaves they become more gray in tint. A brief résumé of the mechanism of stroboscopic perception will make the reason for this clear. Each flash of the light reveals the whole pattern. In the first octave each dot on the second flash falls exactly where the preceding dot was on the first flash. In the second octave, however, the second flash catches the dots midway between the positions occupied at the first flash. The dots therefore fall on a space on the drum that was white during the preceding flash, while the spot that was black on the first flash is now white. This rapid interchange of alternating blackness and whiteness gives rise to a sensation of gray in precisely the same way that it is produced on the color wheel.

E. The standard tone. It was decided to control the pitch of the stimulus tone by synchronizing it with the speed of rotation of the drum. An electric siren was used for this purpose. A toothed iron wheel was mounted on the tonoscope shaft to rotate past the holes of a watch-case type of telephone receiver, the teeth inducing a current in the windings of the receiver magnets as described by *Bunch* (5). This receiver was connected with another of similar type which *O* held to his ear. The fluctuations in the current produced a tone in the second receiver which was quite pure in quality and of a frequency corresponding to the frequency of passage of teeth past the poles of the first receiver. The wheel had 200 teeth, a number corresponding to the number of dots in the fundamental row on the drum of the tonoscope. The intensity of the tone was regulated by adjusting the distance between the toothed wheel and the poles of the generator-receiver.

F. Arrangement for testing voluntary control. For use with the revised test for voluntary control a phonograph turntable and electric pickup were included in the complete equipment.[8] On this turntable was placed the pitch record from the Seashore

[8] The system as described may be also used very conveniently for reading the pitch of tones from any phonograph record.

"Measures of Musical Talent".[9] The tones from the record were transmitted to a telephone receiver worn by *O*, who reproduced the intervals. In this test the tonoscope was run at a speed of 72 r.p.m., checked with 60 cycle current by the C_1 row of dots on the drum. In Table II the tonoscope values, photographically determined, and checked by a large number of readings made directly on the tonoscope, are given for the various tones on the pitch record, side A. The synchronous rotation of the record and the drum made these values correct, regardless of the speed at which the drum rotated.

TABLE II. *Correct readings on the tonoscope of tones in the Seashore pitch record*

Tone		Correct value on tonoscope	Nearest approx.	Error of approx. in parts of tone	Value of int. in parts of tone
Standard		A♯ —.15	A♯ —.15	0.00	
Increment	I	B —.01	B	.01	.65
"	II	A♯ +.36	A♯ +.35	.01	.50
"	III	A♯ +.18	A♯ +.20	.02	.35
"	IV	A♯ +.08	A♯ +.10	.02	.25
"	V	A♯ +.01	A♯	.01	.15

The nearest approximations are given on the hypothesis that the values will be read in terms of twentieths of a tone, or .05 of a tone. The true value of the standard is, therefore, A ♯ – .15 of a tone, or A ♯ minus one and one-half scale divisions; for the first series, the true value of the increment tone is B–.01 of a tone; the approximation given will be in error by only .01 of a tone, *etc.* In giving the test the sung values were read and referred to the true values given in the table.

Accuracy of apparatus and reading. The accuracy of the tonoscope for tests of vocal control of pitch was tested for three variables: (1) the accuracy of the motor, (2) the accuracy of reading sung tones, and (3) reading the vibrato.

A. Accuracy of the motor. In order to avoid the inconvenience of winding a spring motor and the difficulties caused by the decrement in speed as the spring tension becomes less during the period of a single winding, a phonograph motor of the

[9] Columbia phonograph record 53004D.

electric type was adopted.[10] This motor was of the induction disc type, regulated by a governor similar to the one used in the ordinary spring motor. It operated from the common A.C. source.

The accuracy of the motor was tested for the following variables: (1) time required to attain full speed, (2) changes in speed during rise in temperature of the motor, (3) accuracy for consecutive revolutions while hot, both at normal speed and at the reduced speed required for the test of voluntary control, and (4) variations in speed during the day, due to changes in voltage of the A.C. supply. Both the stroboscopic method and the graphic method were used, the motor running under the full load of the tonoscope.

The average time for the motor to attain full speed from a standing start without aid was 17 sec. The tests showed that there was a small change in the speed during the period of warming up. This was measured as follows. The tonoscope was started at room temperature, having been previously adjusted so that the A row was motionless when a tuning fork of 435 ~ was sounded into the transmitter. Readings were taken at 1 min. intervals after this. The average values for each successive 5 min. period showed gains over the original value as follows in a sample test, in ~ : .4, .6, 1.0, 1.0, 1.0, 1.0. A gain of one ~ at the level of 435 ~ is a gain of approximately .25 per cent. This test was checked graphically, using a 100 ~ fork, for the first twelve minutes of running. In every case the change was less than .5 ~ at this level, or .13 per cent. It is recommended, however, that the motor be run from five to ten minutes before using for tests in order to make this change as small as possible.

The revolution to revolution deviations are shown in Figs. 1 and 2, for both normal speed and the reduced speed used with the test of voluntary control. At the reduced speed the figure shows, by the change in curvature of the radial lines, a type of deviation which appears occasionally at this speed. It is of the order of not more than .5 ~.

[10] General Electric induction disc phonograph motor.

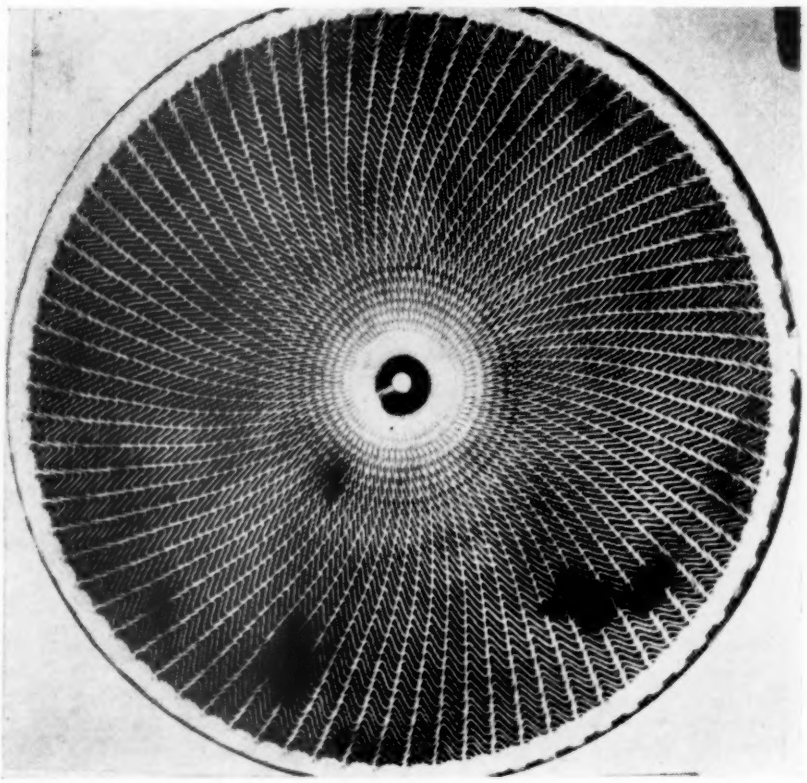

FIG. 1. Accuracy of tonoscope motor at normal speed (100 ~ fork).

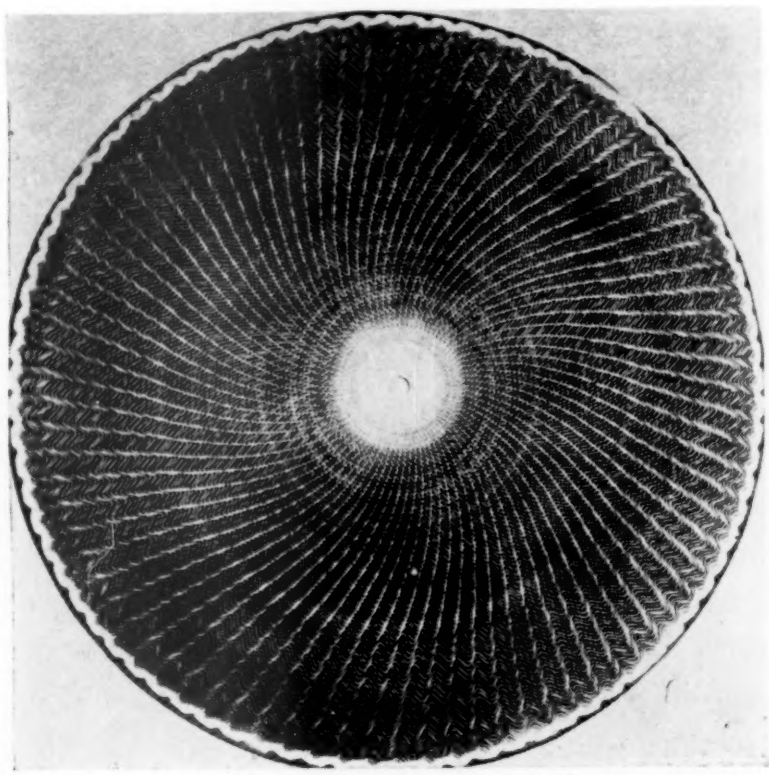

FIG. 2. Accuracy of tonoscope motor at reduced speed (100 ~ fork).

The deviations from time to time during the day were tested by allowing the motor to run 20 min. at various intervals during the day, taking the stroboscopic readings at the end of the warming up period. The differences were so small as to be negligible.

The greatest deviation was found when the motor is forced to pull the load imposed by the electric pickup in the test of voluntary control. The dilemma was this, that the addition of a counterweight on the pickup sufficient to cause no decrement in the speed of the motor, caused a lack of clearness in the tones in the receiver, due to the failure of the needle to track the groove accurately. It is therefore necessary to adjust the speed of the motor while the pickup is on the record. Even then an increase of speed was found as the pickup gradually approached the center of the disc. This change averaged 2 ~ when tested with a 435 ~ fork, a gain of approximately 1 per cent. The constancy from revolution to revolution was as good as when the motor was running free. The increase in speed, since it is spread over the whole three minutes of running is, therefore, negligible, since the singer reproduces each interval immediately after it is sounded.

B. Individual differences in reading the tonoscope. *Miles*(16) has shown that the pitch of tuning fork tones may be read with an error of less than 1 ~ for exposures of one sec. and less. In the present experiment the purpose was to discover how accurately sung tones of durations of one to two sec. could be read.

The problem was attacked by comparing the readings made simultaneously, but independently by the writer and three assistants of various degrees of training in the skill. The readings of the writer represent the level of accuracy gained by him after many thousands of practice readings. The readings were made in a manner exactly similar to that used in actual testing work, —sung tones being used instead of tuning forks or other mechanically steady tones in order to make the situation as nearly analogous to the actual singing situation as possible.

Preliminary comparisons of readings with the first assistant

who was somewhat practiced in the technique, made it obvious that a considerable degree of motivation is necessary in order to attain high accuracy. After a period of practice in which speed and accuracy were stressed, and in which a spirit of friendly rivalry was built up, a series of 70 readings was taken of random tones, one-half of a man's voice, one-half of a woman's voice, sung without vibrato. The readings were made in terms of twentieths of a tone. A second series of readings taken from a scale passage was next read. The results are summarized in Tables III and IV.

TABLE III. *Agreement of two practiced readers on random sung tones.*

Difference in 1/20 tone	No.	Per cent
0.0	40	57
1	20	29
2	10	14

The standard deviation of this distribution is .045 or a whole tone, indicating that during 68 per cent of the time the differences were less than 1/20 of a tone.

TABLE IV. *Agreement of two practiced readers on scale passages.*

Difference in 1/20 tone	No.	Per cent
0.0	58	73
1	19	34
2	2	2

The standard deviation of this distribution is .029 of a tone. showing that a still greater accuracy was obtained in the scale situation, where the factor of anticipation aided the reading.

In an attempt to derive a measure of the minimum amount of practice necessary for accurate reading two other assistants, who were entirely unfamiliar with the procedure were trained. The first of these was able in a half-hour's practice to reduce the standard deviation of the differences from .043 of a whole tone to .022 of a whole tone, in a series of random sung tones. Reading and memorizing four tones out of a scale passage gave approximately as good results, the final standard deviation being .036 of a tone. The third assistant was able to reduce the error,

calculated in the same way, from .072 of a tone to .051 of a tone in 30 min. of practice.

The following conclusions seem to be justified by the tests: (1) a satisfactory degree of accuracy, as measured by the correspondence between the readings of two *O*s, may be attained with a comparatively limited amount of practice in reading sung tones on the tonoscope; (2) the problem of estimating in terms of half divisions on the scale offers no special difficulties; (3) practice, in order to be effective must be strongly motivated. It is easy to fall into careless and inaccurate habits of reading.

C. Reading the vibrato. The vibrato is such an important part of artistic singing that a special study was conducted for the purpose of ascertaining the best method of reading it on the tonoscope. It is essential that singers who habitually sing with the vibrato, many of whom use it quite unconsciously, must be permitted to sing in the normal manner, because the attempt to iron out the fluctuation in pitch distorts the natural singing situation and may lead to errors in pitch not normally present. In addition, inhibiting the vibrato usually forces the singer into improper methods of tonal production.

The appearance of the vibrato on the tonoscope has been described by *Schoen* (18) and *Metfessel* (12). The fluctuation in pitch appears as a pattern in which the middle row of dots representing approximately the mean pitch of the vibrato oscillates back and forth without any progressive motion, while the rows on either side move in opposite directions alternately by a series of short jerks and pauses.

On the assumption that the row which oscillates in a pendular manner without progressive movement in either direction is the tone which is perceived by the listener,[11] and is the one which must be read, a comparison was made between the pitch of this row as given by the tonoscope and a photographic record of a number of sung tones in which the vibrato was present. Model VI of the tonoscope was used. A phonograph record was placed on the turntable directly above the tonoscope drum, so that the

[11] This is the assumption made by *Metfessel* (13, p. 37). Further work is in progress on this problem at the present time.

two were synchronized. Two records were used, one of the bass voice, David Bispham, and one of Alice Nielsen, soprano. A number of tones showing a good vibrato were read, from each of the ranges, high, middle, and low, of each voice. The row of dots on the tonoscope drum which showed a gentle oscillation to and fro, but no progressive movement, was read, and verified a number of times. This pitch was recorded. The same tones were then photographed according to the technique described by *Metfessel* (12) where the phonograph record is synchronized with the drum carrying the motion picture film. *Metfessel* (12) has shown that the error in reading of films in phonophotography is very small. The technique was, therefore, one which yielded results of considerable refinement.

There was, in every case, a very close correspondence between the mean pitch of the photographed tones and the pitch read on the tonoscope. The results for a sampling of six tones are given in Table V in terms of vibrations. The mean pitch of the sung tones and the total range are given for the photographic records. Fig. 3 shows the same results in graphic form for

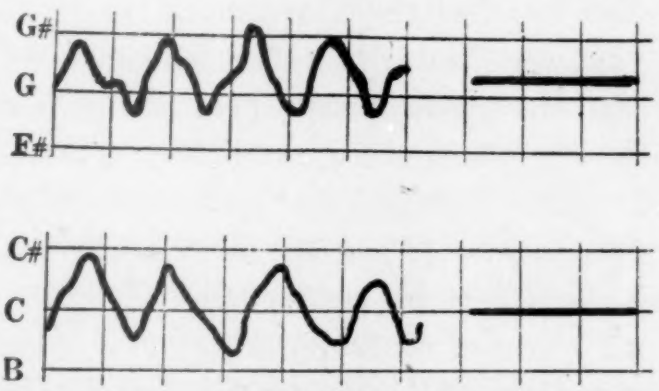

FIG. 3. Comparison of the tonoscopic readings and a photographic record of the pitch of two tones. The curve represents the phonophotographic record, the straight line the pitch as read on the tonoscope.

TABLE V. *Comparison of pitch of vibrato tones as read on the tonoscope and as recorded photographically*

Tone	Singer	Pitch (tonoscopic)	A. M. pitch (photographic)	Range (photographic)
1	Bispham	258.6	258	246–274
3	"	196.5	197	188–205
5	"	129.3	129	123–138
1	Nielsen	460.4	460	445–488
2	"	344.0	346	340–361
3	"	615.6	615	574–643

two of the tones. In view of the close correspondence between the mean pitch of the vibrato and the tonoscopic readings, by the method described above, and because of its relative simplicity in practice, it is the plan recommended for use.

The conditions of stroboscopic vision are such that only fairly steady tones, or tones having a certain degree of smoothness in pitch changes will yield a clear pattern on the drum. Inasmuch as an artistic vibrato is a regular pitch fluctuation of a circumscribed extent (14) it will be seen that the demands of stroboscopic vision and the artistic requirements are very similar.

Through the kindness of Dr. *M. F. Metfessel,* an opportunity was given for the comparison of ratings of a number of vibrato tones on the tonoscope with objective records taken on the *Metfessel* strobophotographic camera (15) of the pitch range, regularity, and period of oscillation of the tones.

Tones from different vocal ranges were sung, intoned on different vowels, with different vocal placements. Preliminary trials showed that there was no significant difference in clearness between the two vowels used, *a* and *u*. Nasal and throaty placements also failed to affect the clearness of the record.

Certain specific conditions, however, led uniformly to a failure of the pattern on the tonoscope drum to become sufficiently clear for easy reading.[12] These were as follows: (1) when there was excessive or irregular fluctuation of pitch in the vibrato, as shown by the objective record; (2) when the vibrato was too rapid,—approximately above 8 cycles per second; (3) in the ranges above G^2 of women's voices, a necessary defect in a tonoscope as small as the present model, the failure to register clearly being caused by the proximity of the dots on the drum; (4) when there was excessive intensive fluctuation in the vibrato causing the brightness of the neon lamps to vary by a large amount; (5) when the singer used an exaggerated vibrato.

It is apparent that the majority of the causes leading to difficulty in reading the vibrato are to be found in peculiarities in the singer, and that these represent, as a whole, defects in the

[12] The exact data are omitted here on account of lack of space, but are filed in the Department of Psychology, University of Iowa.

vibrato according to artistic standards. The general statement may be made that a good vibrato, artistically produced and sustained, can be very clearly read on the tonoscope.

The tonoscope lends itself, admirably, therefore, as a diagnostic and practice instrument for the correction of certain common faults in control of the vibrato, as well as furnishing an objective criterion of intonation. Erratic shifts in pitch of the voice, tremolos, and inartistic vibratos, whether due to improper pitch range, too great irregularity, or too rapid a rate, all display themselves in an unequivocal manner on the tonoscope drum. By the aid of the eye the singer may practice this most necessary attribute of the singing voice until it is under proper control. The frequency of oscillation can be estimated by comparison with a metronome beating seconds. The extent is correct when the dots oscillate through an amplitude of approximately 1 cm. Adequate regularity is gained when the oscillation of the dots is smooth enough for clear and easy reading.

III. Problems in the measurement of vocal control of pitch

In the measurement of any ability as complex as vocal control of pitch there are many problems in the technique of measurement which must be answered. The writer has classified these problems, for the purpose of the present research, under two heads, the analysis of variable factors and sources of error in singing test, and considerations of specific test procedures. Under the former heading an attempt has been made to give a partial analysis of the various factors necessarily associated with tests of vocal control which might influence results in a significant way if uncontrolled, and to evaluate the influence of these factors in terms of the experimental literature now available. In the second section the various historical methods of giving the tests of interval singing and voluntary control and certain modifications of procedure are recommended.

Variable factors and sources of error in tests of vocal control of pitch. The analysis presented here is confined to those factors on which some experimental evidence has been available. Un-

fortunately the list is at present far from complete. Unfortunately also, the evidence is not always conclusive. One of the necessary difficulties the pioneer worker usually faces is that he is compelled to work with uneconomical tools. Where the optical method of reading the pitch of tones has not been available, investigators have been forced to use various forms of graphic techniques. These methods render almost prohibitive the labor of accumulating sufficient amounts of data for statistical adequacy. Many of the studies base their findings on single trials of a few seconds duration by each *O*. Moreover, the number of *O*s has usually been very few. The writer has attempted here to weigh the evidence in the light either of general agreement among the investigators or of conclusions which are based on data possessing at least a fair degree of statistical adequacy. It will be noted that statements of the results of the writer's own studies in the influence of various factors on vocal control of pitch are included in this section. The descriptions of procedure and tabulations of results for these experiments will be found in *Appendix A* of the present paper.

Factors associated with the standard tone. Among the factors associated with the standard tone which have been investigated are, timbre, intensity, duration and pitch, and the time interval between the standard and the reproduction. These will be discussed in turn.

A. Timbre of standard tone. In what appears to be the only controlled experiment on the problem of the influence of the timbre of the standard tone on the pitch of the reproduction, *Miles* (16) found, with five men, differences in both the variability and the constant error between reproductions of tuning forks, the dichord, and the organ pipe, the reproduction of the organ pipe being the most accurate. The differences are small, the group constant errors being, for the fork, 1.2 ~, m.v. .8, for the string, –.8, m.v. .5, and for the pipe, –.1, m.v. .5,[13] and can not be considered adequate statistically. Miles draws up the hypothesis, after an examination of various lines of evidence,

[13] Throughout this paper, absence of sign in statements of constant error is to be interpreted as implying the positive sign.

that in general tones richest in timbre are most accurately reproduced. Comparisons between the results of different investigators using different stimuli can not be made due to the other differences in technique used and the problems of sampling introduced.

The choice of a standard tone depends in large measure on questions of the constancy of pitch and timbre of the stimulus, and the convenience of use in the testing routine. On both of these points the tuning fork and the electric tone generator which is substituted for it in the revised tonoscope are superior to strings and pipes. The timbre is one which is relatively novel for both trained and untrained singers, a fact which is of further advantage. Tests of the tone generator, reported in *Appendix A*, indicate that introspectively its timbre is practically indistinguishable from that of a tuning fork and resonator at low intensities. The pitch of reproduction is practically identical with that of the tuning fork, for nine *O*s.

Practically all of the evidence shows that tuning fork tones tend to be reproduced slightly sharp, particularly by women. Tests with the tone generator will, therefore, tend to yield results slightly sharp with the majority of *O*s.

B. Intensity of standard. *Miles* (16) concluded, on the basis of the results from nine *O*s, reproducing tuning forks at five pitch levels, that increasing the intensity of the standard tone tends to cause a lowering of the pitch of the reproduction as well as general inaccuracy in voice control. The intensity varied from "about as strong as possible" to "as weak as could be heard with distinctness." He concludes, as does *Seashore* (21) in the case of pitch discrimination that the "just perfectly clearly perceptible tone is most favorable for accurate results." In the electric generator of the tonoscope the intensity may be set at the most favorable point where it is then maintained mechanically exact.

C. Duration of standard. No experiments have been made on the influence of the duration of the standard on reproduction by the successive method. For pitch discrimination a duration

of one sec. seems to be most favorable (2). The duration should be long enough for *O* to grasp the pitch clearly in one attentive wave, and short enough so that he may begin the reproduction before fluctuation of attention sets in. A duration of one to two sec. is ample.

D. Pitch of standard. Preliminary experimentation with a number of *O*s who were reproducing forks of the order of 256 ~ with high accuracy, both at that level and an octave lower, indicated that some individuals were unable to reproduce the pitch of low tuning forks with an accuracy nearly as great. The results of further experimentation, reported in *Appendix A,* confirmed this finding, in the case of some individuals, among them some who were well trained musically, while others were able to reproduce low forks with an accuracy comparable with the results when reproducing higher forks.

Cameron (6) found similar results in an intensive series with one *O*. He reports that "By far the greater error occurs in connection with the low tones." He also notes that this finding accords with introspections. The difficulty seems to be a perceptual one, associated perhaps with the volumic attribute; the introspective reports usually indicated that the tones had a "hazy, indefinite" pitch. Pitch discrimination, on the other hand, seems not to be affected in a similar way, since the average threshold in ~ is approximately the same at 128 and 256 ~ (28). The fact that *Weaver* (29) found *O*s who were making gross errors in reproduction may also be explained partly on this ground.

For this reason it is recommended that in standard tests for reproduction of a tone, the stimulus be of the same pitch for all, the men reproducing the pitch an octave lower. Repeated observation has shown that this is the plan which an *O* will spontaneously adopt when asked to reproduce the pitch of a 256 ~ fork without other instruction.

E. Time interval between standard and reproduction. All writers agree that tones are reproduced less accurately after a time interval has elapsed between the standard and the reproduction. *Berlage* (3) states that the accuracy decreases regularly

with the interval. *Cameron* (6) states that simultaneous reproduction, " . . . probably aids in exactness, although the figures . . . are not very conclusive on this point." The time interval required to produce a large diminution of accuracy, is, however, quite long, 10 sec. or more. *Weaver* (29) found that his *O*s could reproduce a tone with fair accuracy five minutes afterward, the diminution being, for 23 men, from a group error of 6.07 ~ to 11.07 ~, for 20 women, from 8.71 ~ to 11.47 ~. Simultaneous reproduction has probably the greatest musical validity. Since it has been shown, however, that tonal memory does not become a significant factor when the interval is very short, reproduction by the successive, rather than by the simultaneous method is recommended for standard procedure, chiefly because of the better laboratory control established. The singer can not, in this method, take advantage of secondary criteria, such as beats, which he may do in simultaneous reproduction, especially when the stimulus is given through a telephone receiver held to the ear, as is done with the electric generator. The temporal interval should be as short as possible, not over one sec.

Motor factors. The motor factors which have received consideration are: vowel quality, pitch variations during the singing of a tone, range of voice, stereotypy, and the vocal intensity.

A. The effect of vowels. From the time of *Berlage* (3) the factor of vowel quality has been recognized as a variable in pitch control. He found, using three *O*s, that in the reproduction of one's own voice, vowel changes reduce precision. He notes in particular, that when *u* is used as the standard and *i* as the reproduction, that there was a tendency for *i* to be sung flat, and *vice versa*. This finding is in opposition to the results of *Miles* (16), who used tuning forks as standard tones. Miles states on the basis of 6 *O*s that " there is a tendency for the vowels to fall into three groups: namely, (1) *o* sung the lowest, (2) *a*, ɛ:, and possibly *u* sung moderately sharp, and (3) *i* sung decidedly sharp." [14] The hum, presumably the most neutral, had a place with *a* and ɛ:. A study conducted by the writer on this

[14] The vowel symbols are translated into the nearest equivalents in the international phonetic system.

point, reported in *Appendix A* fully confirms the results of Miles in so far as the same vowels were used. Berlage explains the phenomenon as the assimilative effect on the tonal idea of the vowel formant; Miles seeks to explain it in terms of "the dominating overtone in a vowel clang." It was the writer's original hypothesis that the explanation might be found in terms of the vowel triangle, and so two vowels were chosen from each of the three types, frontal, neutral, and back vowels, as follows, *i, e; a, ɔ:; o, u.* The vowels *i* and *e* were sung most sharp, followed by *a, ɔ:,* and *u,* with *o* being sung the lowest. This follows the order of frontality, except for the reversal of *u* and *o.* It seems at present best to explain the phenomenon in terms of simple considerations of muscular tension. In the production of *i,* for example, the whole vocomotor apparatus is brought under considerable tension, due to the fact that the tongue is raised high and brought forward. In the production of *o,* on the other hand, the tongue is relaxed. These changes in tension vary the position of the larynx in phonation to a sufficient amount to cause the changes in pitch which are found. The differences between the extreme vowels were usually larger than the threshold of pitch discrimination of pure tones by the *O*s, so that differences in quality undoubtedly mask the differences in pitch.

From the point of view of standard tests, it would seem advisable to use one of the neutral vowels; *a* or *u* is therefore recommended. With the electrical system at present in use with the tonoscope, *u* is to be preferred because it yields a slightly clearer pattern of dots under all conditions.

B. Pitch variations during the singing of a tone. There is general agreement among writers that the first few tenths of a second in the singing of a tone are marked periods of adjustment (3, 6, 17). By far the most important pitch change in this period is a rising "scoop" in the attack. Phonophotographic studies made in connection with this research agree entirely with these findings (Fig. 4). The time taken for the preliminary adjustments is seldom more than the first three tenths of a second.

This rise in pitch in the attack seems to be a fairly universal phenomenon, as it occurs also in the singing of artists (18).

Aside from this preliminary period of adjustment, pitch deviations have no systematic trends, but vary irregularly except when the singer has a vocal pitch vibrato. Cameron (6) found that the latter periods of tones held for durations of 8 to 16 sec. tended to be sung sharp also. The sharping of the release is also characteristic of the singing of trained artists (18). No adequate physiological explanation of this phenomenon in the singing of single tones is apparent at present. It may be due to overcompensation as the breath approaches more nearly the residual value, and the chest is contracted. In melodic passages

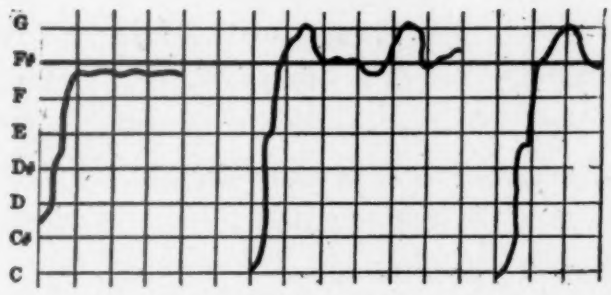

FIG. 4. Phonophotographic studies of attack. Divisions on abscissa represent .1 sec.

the release is undoubtedly conditioned by the factor of anticipation of the following tone.

The best time to read the pitch of a tone, therefore, is immediately after the initial period of adjustment, and before the later irregularities appear. Since 2 to 3 sec. is ample time for reading the pitch of a tone on the tonoscope, the sharping in the release should not appear until after the reading is completed. In the stroboscopic method, irregularities during the singing tend to be smoothed out, so that the pitch registered on the drum tends to be the average pitch of the tone. In case of the vibrato a special method of reading has been developed which has been described above.

C. Range of voice. In the study of the influence of vocal range on accuracy of singing, it must be borne in mind that there

are two possible systems of measurement in which the data may be expressed—absolute and relative differences in frequency, and that results by the two methods will necessarily be contradictory in character. Relative units having been chosen for Model VI of the tonoscope, the present discussion will interpret the data from this point of view entirely.

In a carefully conducted study of this factor with 17 men, covering five different levels of pitch, adjusted in each case to the vocal range of the individual, *Miles* (16) concluded that "taken as a whole these records show that accuracy in the reproduction of the pitch of a tone, as measured by the average error (E) with its mean variation (m.v.) the average of the constant errors (C.E.) and the general tendency of the constant errors (G.C.E.), tends to be a constant in terms of vibration frequency." The slight tendency toward deviation from this constant value in ~ was in the direction of decrease in accuracy with rising pitch. This change was most marked on the highest tone reproduced. *Berlage* (3) found that the variable average error increased with rising pitch in the reproduction of an outside standard. In the reproduction of one's own voice, there was a tendency for accuracy to remain constant in terms of ~, therefore to increase in relative terms. *Cameron's* (6) results for six *O*s show an increase in accuracy with rising pitch in terms of ~, a result that would give a still higher increase in relative terms. The change was most marked, however, at the very low ranges. *Seashore* and *Jenner* (24) found, for minimal change, a tendency for the values to remain constant in term of parts of a tone. The results of the present writer, reported in *Appendix A,* on interval singing, suggest that the major third is sung equally accurately at all ranges in terms of relative units, except that at the very high range there may be tendency to sing the interval flat. The evidence is therefore at present conflicting. In reproduction of a tone there is rather general agreement that accuracy is greater in relative units at the upper half of the vocal range. The available data support the view that accuracy is constant in relative units in situations where intervals are sung, minimal

change being considered as a very small interval.[15] The data on reproduction are in harmony with the data on pitch discrimination in that there is a tendency toward constancy in terms of ~ (28). The best procedure in tests of reproduction is undoubtedly to sample the accuracy at two or more vocal levels. Since interval tests necessarily cover a wider range the chief caution should be to keep as near the middle of the range as possible. The octave from middle c in both directions approximate this value for most individuals.

D. The stereotyped effect. There exists with all *O*s, as has been noted by *Cameron* (6) and *Brennan* (4), a tendency to fall into a rut or kinæsthetic set in all types of singing where test requirements call for several repetitions of a given task. The effect may be ascribed partly to perseveration of the kinæsthetic image, partly to a decrease in the effectiveness of the stimulus through wandering of attention as fatigue and boredom set in. Large individual differences are found in the effectiveness of the variable.

The influence of stereotypy may be minimized by a "rotating" plan of testing. It has been found that ten trials on a single task, such as reproducing a certain tone, or singing a certain interval, is the maximum number which should be given at one time, and a smaller number is better. When the effect begins to appear within such a short series as this the experimenter may check up on the observer with the remark, "Attend to the stimulus more carefully", or "You are not doing as well as at first." Stereotypy, if it appears in a pronounced form, should be noted in the record, as it is probably of some diagnostic significance in the final evaluaton of results. Every vocal teacher is familiar with the type of student who "gets off key" and finds difficulty in getting back again.

[15] The whole question of the accuracy of vocal control in relation to the range of voice is in need of further study, as is the problem of perceptual discrimination in intervals at different levels. There may be a true difference between the threshold for interval discrimination and the threshold for pitch discrimination at different pitch levels. The problem of the influence of "register changes" in the voice is also an important one on which no experimental data are available at present.

E. Voice intensity. *Miles* (16) has shown that there is a general tendency to sing sharp when reproducing a tone loudly, but that the loudness of the voice does not materially affect results for reproductions of weak or medium intensity. Data obtained during the present research and reported in *Appendix A,* indicate a slight tendency to sharp the louder tone in the singing of intervals, if very large differences are made in the loudness of singing. These findings are consistent with our general understanding of the physiology of phonation. Observation has shown the effect to be particularly marked in the reproduction of tones by young children. It is probable that conscious effort must be utilized to counteract the tendency. Instructions to sing rather softly will usually be sufficient to keep this source of error under control.

Special factors affecting singing of intervals and voluntary control. The special factors affecting results in tests of singing of intervals and voluntary control have received less attention in the literature than the factors affecting reproduction. The factors to be discussed are, influence of the pitch of the reproduction on the singing of intervals, the influence of the melodic situation, of progressive error in scale passages, and the influence of the variant tone on the reproduction involuntary control. As has been pointed out, several of the factors already mentioned also affect singing of intervals and voluntary control.

A. Pitch of reproduction and singing of intervals. In the measurement of the accuracy of singing intervals from a standard tone, the question whether the interval value should be reckoned from the pitch of the standard tone or from the pitch of the reproduction has been variously answered. *Gaw* (8) used the former method, while *Brennan* (4) advocated the latter. In considering the situation, the experimental evidence seems to be quite clear on one factor, namely, that *O*'s singing of the interval is affected to a greater degree by the pitch of his own reproduction than by the pitch of the stimulus. In a sample test situation, with 15 *O*s, ten trials each in singing the major third, the correlation between the tendency to deviate in a given

direction from the standard tone, on a given trial, and to deviate in the same direction in the intonation of the interval, was .62, P.E. .04. This finding is consistently borne out by internal evidence from the test results of the present research. A singer who starts sharp, will tend to continue to sing sharp in the immediately following interval tones. In the same singer, accidental flatting in the reproduction of the standard tone will, in general be accompanied by a lowering of the pitch of the interval tone from the usual point for him. The kinæsthetic and auditory sensations attendant upon the reproduction of a standard tone seem to outweigh the influence of the standard on the interval sung. This being true, in tests where the purpose is to measure the degree of control over interval singing possessed by an individual, the interval should be measured *as sung* by reading both the reproduction of the standard and the pitch of the interval tone.

B. The melodic situation. The high validity of measuring interval control in actual melodic situations makes it desirable to use this technique of measurement. But it raises the question of whether the melodic situation influences the intonation of intervals.

Abraham (1), in a study of phonograms of 23 *O*s including both trained and untrained singers, found that the melodic situation influenced intonation. Some of his findings in regard to the intervals between successive notes were: unisons tended to arrange themselves in intonation according to the melodic tendency of the moment; octaves were sung consistently too large; other intervals were sung too large when the melodic tendency was upward, too small when the melodic tendency was downward; melodically important tones (*Haupttöne*) tended to draw unimportant neighboring tones so that the intervals between them were sung too small. In a study, described in *Appendix A,* by the writer on this question, with 16 *O*s, chiefly musical but untrained individuals, differences in intonations were found when calculated both from the keynote as a base, and between notes within the melodic passage, in scale and melodic situations. It was not found possible, however, to explain these differences

consistently in terms of the laws laid down by Abraham. The results seemed to indicate that the scale position from which the interval was sung was the most important influence determining the intonation. It seems quite certain in tests of interval control given in melodic situations that the influence of the melodic pattern must be taken into account in the interpretation of results.[16]

C. Progressive error in scale passages. In the present investigation differences were found between the intonation of certain notes in scales when sung upward, as compared with those sung downward (*Appendix A*). There were, however, no evidences of progressive error for the group as a whole. An examination of the tables of individual constant errors in interval singing in *Appendix B* will show that in some cases there appears to be evidence of progressive error. The instances of systematic error on certain intervals, particularly the leading tone, is more characteristic of the group as a whole. Probably the best procedure, however, is to require a reproduction of the keynote between each note of the scale, in order to avoid as far as possible this effect.

D. Effect of variant tone on reproduction of standard in voluntary control. The possibility of simplifying the technique of testing voluntary control by omitting the readings of the standard introduced the question of whether the reproduction of the variant tone might affect the pitch of singing the standard when the variant tone came first. The influence of this factor was determined in the present study from an analysis of the attempts of the *O*s to imitate the intervals of the pitch record of the Seashore "Measures of Musical Talent". It was discovered that the reproduction of the standard was slightly but not significantly higher when the variant tone was sounded first, the variant tone being always higher in this test. The results suggest that in careful work the pitch of both the reproduction

[16] The question of artistic intention also enters the problem as a variable. The evidence from studies not yet published seems to be that conscious deviations are made by artistic singers in various melodic situations, for example, excessive sharping of the leading tone in final cadences, and so on. *E* must bear these facts in mind when planning test situations.

and the singing of the variant tone be read each time, and that the true value of the interval be calculated by subtracting these values. This conclusion is also supported by the evidence presented concerning the singing of intervals in general.

Subjective factors: (A) Emotion. Travis (27) has shown that emotional upset results in greater variability in pitch in sustained tones in normal subjects. Motor control as a whole may be considerably disturbed as a result of too great emotional tension. *E* must try by all means possible to put *O* at his ease in the test situation, substituting for embarrassment the competitive spirit and the desire to make a good score.

B. Distraction. Cameron (6) and *Sokolowsky* (26) have investigated the effect of distraction on vocomotor control of pitch. According to *Cameron,* auditory distraction causes the sung tone to vary in pitch either toward the distracting tone, or away from it. "Sung tones varying from the standard under the effect of distraction are usually harmonious with the distracting tone. When the distracting tone is inharmonious with the standard tone, distraction is more likely to occur than when the two tones form a harmony. A person may more or less closely imitate a tone which he has heard when engrossed in singing another tone of a standard pitch."

Sokolowsky concluded that there was much greater inaccuracy in singing with auditory distraction than in imitating a tone without distraction. In test procedures of the type recommended here, auditory distraction must be eliminated as far as possible.

C. The instructions. As in all other careful psychological work the instructions must be explicit and standardized. Preliminary trials enable *E* to make sure that the instructions are being properly carried out.

D. Knowledge of results. Except in systematic training series it is the purpose of the vocal tests to measure the ability of the individual to perform the required tasks under carefully controlled laboratory conditions without external aid. For this reason knowledge of results is usually withheld. Definite improvement in the accuracy of singing with knowledge of results

has been demonstrated by *Seashore* and *Jenner* (24) and *Knock* (11).

E. Motivation. This is one of the most difficult variables to control in any test. Under insufficient motivation attention wanders, leading to stereotypy of performance and undue laxity in the auditory check-up by *O* of his singing. It is essential that *E* endeavor to insure a proper degree of motivation through the cultivation of a proper attitude toward the tests.

Problems of procedure in tests of interval singing and voluntary control. Historically procedures for the measurement of interval singing may be divided into two groups, measurements made on the ability to sing intervals " pure " or in isolation, and the analysis of interval values out of melodic test situations. In the researches of *Seashore* and *Jenner* (24), *Knock* (11) and *Kerppola* and *Walle* (9) the former method was used. The first attempt in this laboratory to measure the singing of intervals in a melodic situation is reported by *Seashore* and *Mount* (25). The major third taken from the melody " America " was used as the measure of the ability to sing intervals. The same procedure was followed by *Gaw* (8) and *Brennan* (4). *Seashore* and *Mount* also report the use of the natural scale.

Each of the classes of procedure has its own values and difficulties. Presumably, singing the pure intervals uncomplicated by any melodic setting, represents the best control of the variables in the situation. The chief objection to the method is found in testing relatively naïve and untrained individuals. These usually find it very difficult to sing any interval called for without much preliminary fumbling which usually takes the form of singing scales and melodies until the desired interval is fixed in mind. It is thus apparent that in such cases the method of testing " pure " intervals defeats in large measure its own end since the required interval is recalled through some process of melodic trial and error. The method is best adapted for work with musically trained *O*s.

In terms of the final objectives of pitch control, tests which draw the measures from melodic sequences seem to be most valid.

Such test situations approach most nearly the actual everyday situation in singing. The procedure has also other technical advantages. It is admirably suited for work with young children and untrained singers. A further advantage of this method comes from the ease and economy with which measurements can be made. By the use of the tonoscope a reader can memorize as many as seven or eight different interval values per trial for recording. The chief objections to the method are: (1) loss of exact experimental control introduced through the influence of the melodic passages and (2) the problems introduced in the quantification of results. The first difficulty makes it necessary either to standardize each test situation independently or to include a large variety of melodic patterns. The chief problem in the quantification of results of interval tests given in melodic situations is that of deciding whether the interval values should be calculated between successive notes or whether all tones should be related to the keynote. There exists, as has been pointed out, a delicate balance of influence between the effect of accidental and systematic errors in the melodic progression, and the general tonality of the melody as set forth by the pitch of the keynote, a balance which is difficult to evaluate analytically. *Metfessel* (13) used both measures, *Abraham* (1) only the intervals between successive notes. The problem must be answered partly at least in terms of the particular purpose of *E*. In simple and brief test situations the "keynote" intervals are probably the most convenient and valid. The longer the test situation the less validity such a procedure will have, unless the particular purpose of the student is to discover the accuracy with which an individual can maintain a given tonality. In advanced studies of such factors as the ability to modulate correctly without aid, or in studies of control over difficult intervals the proper measure will undoubtedly be intervals between successive notes.

Three fairly distinct procedures have been used historically in the test for voluntary control. In the method developed by *Miles,* (16), under *Seashore's* direction, the *O* was required to reproduce the pitch of the standard fork and then to reproduce

immediately the pitch of the variant fork. The direction of pitch change of the variant fork was always upward. *Cutshall* (7) varied this procedure by sounding both the standard and the variant, requiring *O* to imitate the interval heard. *Seashore* (19) originally suggested and later *Gaw* (8) and others required *O* to reproduce the standard and then to produce voluntarily the smallest change in pitch of the voice possible, hence the alternative term often used of " minimal change."

In theory the ability is the analogue in the motor field of pitch discrimination in the sensory field. The chief difficulties in the use of the test have been those of a practical nature involved in the development of an adequate testing technique.

The method recommended by *Miles* is open to two objections. It is, in the first place, very difficult to give, requiring either an assistant to manipulate the forks or great skill on the part of *E*. In the second place, the method tends to degenerate, unless very carefully given, into a test of the reproduction of tones, on account of the time interval between stimuli. The chief advantage of the method is the degree of experimental control obtained through the use of definite stimuli for *O* to imitate.

The method of minimal change has proved in actual practice to be open to still more serious objections. Extensive experience in giving the test under laboratory conditions has led to the following observations of the types of difficulty to be met in giving the test by this method—see also *Brennan* (4). 1. While the novelty of the task is one of the chief values of the test of voluntary control, this advantage is gained, when no objective standards are used, at an inordinate cost in testing time, since with every *O* a rather lengthy preliminary series must be gone through. 2. Scores on the test when given by this method reveal inconsistencies with scores for the same individuals on other tests of vocal control, due chiefly to the operation of non-musical factors. Scores are influenced, for example, to a marked extent by the accidental discovery on the part of some *O*s of " tricks " of response, such as merely changing slightly the intensity of the voice, or craning the head forward. 3. The verbal instruc-

tions influence the performance in a marked way. Higher scores are made by *O*s when instructed to concentrate on throat kinæsthesis, rather than on singing the smallest interval they can hear. 4. Stereotypy of response is more likely to appear than when *O* has a changing series of a standards to imitate. The chief advantage of the method is ease of administration; its fundamental disadvantage, lack of experimental control.

On the basis of these considerations a modified procedure was developed in the present research which seems to be relatively free for the objections enumerated, and is very easy to administer. The singer was set the task of imitating the standard intervals on the pitch record of the Seashore "Measures of Musical Talent." The following advantages are claimed for the method. In the first place, whatever values are to be gained from the use of objective standards are preserved. By this technique, both the standard and the variant tone are sounded before *O* sings either one. The objection that the test tends to become, in unskilful hands merely another test for reproduction is thus entirely obviated. A further advantage of this procedure is that the changes are made upward and downward in random order, a plan which forces *O* to listen carefully to the stimuli. It seems to the present writer to be invalid musically to accept, as *bona fide* data, changes in pitch which are too small for *O* himself to hear, a condition which has undoubtedly existed in all previous methods of measuring this ability, where the changes were all made in one direction. Failure to hear the differences in pitch, a point beyond which it is illogical to expect that *O* can really exercise "voluntary control" in a musically valid way, can be immediately checked by the fact that *O* begins to make the pitch changes in the wrong direction. This seems to the present writer to be the only way in which "tricks" of vocal manipulation can be avoided and *O* held to a type of performance which has musical significance.

The objection that the illusion of overestimation of small intervals is a significant factor is met by the fact that both the data of *Miles* (16) and our own data show very large individual differences in the degree to which this factor operates.

While insufficient data are available as yet regarding the musical validity of the test, it is believed that many of the standing objections to the test as formerly given have been eliminated. The test is normally restricted, with average individuals, to the A side of the record, where the objection of the illusion of small intervals has less force. Only in the case of exceptionally good *O*s need the B side of the record be used.

IV. The Experimental Series

In order to obtain certain quantitative measures on tests of vocal control of pitch a series was chosen for experimental trial consisting of measures of each of the three basic abilities. Reproduction of a tone was measured directly at one vocal level. Interval control was measured by taking the average of three test situations, singing the scale up, singing the scale down, and from the intervals selected from the melodies "America" and "Annie Laurie".[17] Voluntary control was measured by the revised procedure described above.

Test procedures. Before beginning measurement a definite attempt was made to establish rapport between *E* and *O*, to rid *O* of any emotional tension and to familiarize him with the procedure. The purpose of the test was explained to *O*, and, where he showed interest the mechanism of the tonoscope was demonstrated. During a preliminary series of trials of reproduction the proper placement of *O* before the horn was determined and minor faults, such as excessive "scooping" in the attack, were corrected.

In the test for reproduction and interval singing a 256 ~ [18] tuning fork was used, the men singing an octave lower. The

[17] This method of testing the accuracy of interval singing is, therefore, in a sense a compromise between a test of "pure" interval singing and the method by sampling of melodic situations. This choice was guided by the general purpose, which was to sample as widely and as validly as possible, within the limitations of time and experimental technique, the abilities of the normal and slightly superior adult in interval control.

[18] The tuning fork was used because the electric tone generator had not been completed at the time the tests were given. The correspondence between the fork and the tonoscope was checked at frequent intervals by the stroboscopic technique. Practically identical results would have been obtained through the use of the electric tone generator.

instructions for the test of reproduction were, " I will sound a tone, you are to reproduce the pitch as accurately as you can. Use the syllable 'la'. Begin to sing as soon as you have the tone clearly in mind, and hold the tone as steady as possible for about two seconds. Sing with a moderate intensity of voice. Sing with as good quality as you can, but remember that a correct reproduction of pitch is the important thing. Report any sources of error, such as distraction, lack of clearness in the stimulus tone, and the like, so that those trials may be rejected." No measurements were made until *O* appeared to be carrying out the directions to the best of his ability. During the progress of the test it occasionally became necessary to check up *O* with the caution, "listen more carefully to the standard tone", but no hint of the accuracy of singing was given at any time. The stimulus was stopped as soon as *O* began to sing. It will be seen that each item in the instructions was designed to standardize certain of the important variable factors in singing. The use of " la " is defended on the basis that it represents a middle vowel in the pitch series in the reproduction of vowels. Twenty trials were taken in groups of ten separated by a short pause.

In the test for singing intervals, the following instructions were given in the " scale up " section of the test: " You are to sing the natural scale upward, from this tone as a keynote, using the syllable 'la'. Sing with a moderate intensity of voice, being particularly careful to avoid any large changes in intensity as you go up the scale. Sing with as good quality as you can, but concentrate your attention on getting the pitch of the scale steps as exact as you can. Sing at a comfortable tempo, breathing, if necessary, between F and G." Several preliminary trials were usually given on the test. Measurement was begun when *O* was singing what was in his opinion an accurate scale. The same instructions were given in the " scale down " section, except that the word " downward " was substituted for the word " upward ". In this section *O* reproduced the standard tone an octave higher.[19]

[19] The tests for reproduction and singing of scales have been since modified [see Manual by *Seashore* (23)]. Reproduction of a tone is now sampled at two vocal levels an octave apart. The scale test has been decidedly improved by requiring *O* to sing a reproduction of the standard tone between each of the scale notes.

The directions for the "America" section of the test were, "You are to sing the first two phrases of the song 'America', on the syllable 'la'. Sing with only moderate intensity and good quality of voice, concentrating on accuracy of pitch." For the "Annie Laurie" section the directions were, "You are to sing the first two phrases of 'Annie Laurie' as follows: first reproduce the standard tone as accurately as you can. This gives you the keynote for the melody. From this as a base, sing the first note of the song which is a major third above, that is the song begins on 'mi'. Use the syllable 'la'. Concentrate on singing with as accurate pitch as possible." Practice trials were allowed as before until *O* was satisfied and was following directions exactly. In no case did *E* sing the melodies for *O*, though he did correct verbally any textual errors in the singing.

The tests in the two series were broken up according to the following schema:

1. Reproduction of standard, 20 trials, separated into two halves by a 1 min. interval.
2. Singing scale up, 5 trials.
3. Singing scale down, 5 trials.
4. Singing scale up, 5 trials.
5. Singing scale down, 5 trials.
6. Singing "America", 5 trials.
7. Singing "Annie Laurie", 5 trials.
8. Singing scale up, 5 trials.
9. Singing scale down, 5 trials.

A constant watch was maintained by *E* for signs of fatigue, voice strain. and stereotypy. Occasionally a test was discontinued when the voice strain became serious. In cases of stereotypy, the test was in interrupted momentarily.

The test for voluntary control was given later. The instructions were, "You will hear a series of very narrow intervals played by the phonograph record. Listen carefully to the interval played and immediately imitate it as accurately as you can, using the syllable 'la'. Concentrate the attention first on listening to the standard interval, shifting immediately to your own reproduction of it. As the test moves rather rapidly, you must reproduce the interval quickly, trusting your first impression." Several practice trials were taken. During the practice trials, *E* cor-

rected as far as possible any deviations from the standard procedure. The record was slowed down so that the standard tone had the pitch of G. This slowing down of the speed of the record brought the pitch of the tones nearer the middle of the vocal range, and gave somewhat longer intervals between trials. The speed was checked at frequent intervals with a tuning fork.

Quantitative treatment of data. All of the reproductions of the standard tone were read and recorded directly. Due to the impossibility of memorizing all of the tones in one trial in the interval tests the following method was adopted. In the scale situations, *E* read in alternate trials the two series, C, D, F, A, and C; and C, E, G, B, and C. This forced *O* to sing twice as many scales as would otherwise be required, and accounts for the larger number of trials in the schedule above. From "America" the syllables "my", "-try", "sweet", and "of" furnished the tonic and the first three intervals of the scale. From "Annie Laurie" the syllables, "-wel", "braes", "bon-", and "where", were chosen in order to complete the series of intervals of the major scale. This selection of notes also made it possible for *E* to read all of the tones in each trial. In view of the extreme simplicity of the tests used here, the "keynote intervals" were calculated, rather than the intervals between successive notes. Thus errors in the individual's reproduction of the keynote were held constant by subtracting them from the errors on the interval tones, according to the arguments already stated. In the "scale down" section the reproduction of the upper tone was taken as the "keynote". The pitch of both tones was read in the test of voluntary control and the values subtracted, errors being given in terms of the true values of the intervals. The score was the cumulative average error.

A complete description of the accuracy of pitch for the purpose of these tests may be obtained by the use of three measures, the constant error (C.E.), the average error (A.E.), and the average deviation (A.D.) or standard deviation (σ). The C.E. represents the algebraic difference between the pitch of a tone as sung and the true value of the tone. Positive values indicate

that the tone was sung sharp, negative values that it was sung flat. In the case of intervals, the positive sign indicates that the interval was sung larger than the true value. The A.D. or σ is a measure of the individual's variability about his own mean, disregarding the true value of the note. The A.E. is calculated by averaging the deviations from the true value without regard to the algebraic sign. It is a measure of the general efficiency of singing, compounded of both errors of C.E. and variability in indeterminate amounts.

All of the measurements were made in per cent of a whole tone. In measures of interval singing parts of a tone as units are essential, since the interval is by definition a ratio of frequencies. The deviations were calculated from the tempered scale.

The tests of reproduction and interval singing were given to 47 individuals, 14 men, 14 women, and a group of 19 women, voice students from the University of Iowa School of Music.[20] The revised test for voluntary control was given at a later time to 18 individuals. All of the individuals tested were, therefore, university students, chiefly graduate students. The following discussion is based on the results of the test which are presented in Appendix B.

Reliability of the tests. Determinations of the reliability of tests of vocal control of pitch, as far as the writer's knowledge goes, have never been made. One of the chief purposes in giving the present series of tests was to obtain data for such computations. In evaluating the coefficients obtained here it must be borne in mind that the group tested represented a group of rather narrow range of talent, selected from those above the average in musical ability, and that the reliabilities given here probably tend to be lowered somewhat by this selection.

The reliability of the test for reproduction, by the method of chance halves with 27 cases, was .94, P.E. .02, when the A.E. was used as a measure. The revised form of the test recom-

[20] The tests were given to the main group by the writer, and to the music school students by Miss Grace Watkins, graduate student in music and psychology.

mended in the manual (23), sampling the ability at two pitch levels with twenty trials each, should yield, therefore, a fairly satisfactory reliability.

The reliability of the test for interval singing was determined by repeating the test one week later. Coefficients were calculated for three measures, the C.E., the A.D. and the A.E. The correlations compare the various measures on each individual for each tone of the scale with the same measure a week later. The reliability for C.E. was .67, P.E. .03, which is only moderate, but indicates a tendency for each individual to repeat his own constant errors in intonation. Selection again undoubtedly operated to reduce the reliability in this test. The test should also have been made somewhat more difficult in order to obtain better differentiation. The correlation between the tests taken a week apart is also more rigorous than the method using chance halves. The correlation for A.D. was low, being only .34, P.E. .05. This low reliability is attributed to the influence of stereotypy, which always tends to appear in poor singers more than in good singers, but which operated to reduce the range of talent in the test still more. The r for average error was .64, P.E. .03, a value which is comparable with the value for the constant error. In this measure stereotypy did not handicap the better singers, since the deviations from the true value of the notes are taken into account.

The reliability for the revised test for voluntary control was .98, P.E. .002, by the method of chance halves, using the cumulative A.E. as a measure of accuracy. This is in spite of the fact that the reversals of direction tend to break up stereotypy.

General accuracy of singing: group results. In terms of the C.E. the results of the present study agree with those of *Miles* (16) in that the men as a group reproduce a standard very accurately and that women tend to sing slightly sharp, this tendency being even more marked in our results than in those of *Miles*. The small differences found between the present results and those of *Miles* can be accounted for in terms of sampling errors. *Miles* did not calculate the A.E. for reproduction. An

interesting comparison may be made here between our results and those of *Weaver* (29) who tested 23 men and 20 women in simultaneous reproduction of tuning forks, summarizing his results, with one trial for each *O* after preliminary practice, in a measure which approximates in meaning our A.E. He found, converting his data into parts of a tone, a mean error for the women of approximately .16 of a tone, for the men of approximately .64 of a tone, results which are very much larger than those of the present study. In the group tested by the present writer no errors were found as great as the mean errors in *Weaver's* results for men, and the mean error for women was just over half as great.

In the interval test there is a general tendency in terms of C.E. for the smaller intervals to be sung more accurately than the large in all of the experimental groups, the difference being least in the music school group. The A.E. also tends to be greater on the larger intervals. These results are in accordance with the findings of *Seashore and Jenner* (24) and *Abraham* (1). The sharping of the leading tone and the octave are the most characteristic deviations for the groups as a whole. The variability within each group ($A.M._{A.D.}$) tends to be decidedly constant.

There are no extensive published studies on the accuracy of interval singing. The results of *Kerppola* and *Walle* (9), whose *O*s reproduced a 100 ~ fork, show higher accuracy in all four of their groups, the entirely unpractised choir singers, singers of high standards, but not professional, and directors of singing, than was found in the present research. The twelve *O*s of *Knock* (11) show values in the first unaided series quite comparable with those of the present study. The six men in the study of *Seashore* and *Jenner* sang in the first series before training with an accuracy within the range of variation found in the present series.

In the test for voluntary control in the present series the gradual increase of the C.E. with the decreasing size of interval step is the most outstanding group result, a point which agrees

with the results of *Miles* (16). This effect is due in part to the overestimation of small intervals as *Miles* suggests, but probably due in part also to actual inability on the part of some of the *O*s to sing the smallest intervals required, with genuine auditory control. In defense of this statement several considerations may be brought forward. In the first place the absolute size of the intervals sung tended to decrease with practically all of the *O*s up to a certain point, a fact which supports the contention that the objective standards serve to make the task definite in the mind of the singer and to assist him in working down to his limit of voluntary control. Again, the original data sheets show that a number of *O*s had already begun, on the smallest intervals of the series, to make the pitch changes in the wrong direction. This being true it is argued that for these *O*s the limit of effective voluntary control had already been reached. Lastly, very marked individual differences are apparent in the accuracy with which the intervals were imitated, indicating that as far as this test was concerned there were operating over and above the general tendency to overestimate small intervals, true differences in the auditory and vocomotor equipment of the *O*s. The A.D.'s are remarkably constant.

In comparing the accuracy of singing in the different tests, it will be seen that the accuracy is highest for men in reproduction of the standard, and in the singing of the narrower intervals. With the women the accuracy of singing the narrow intervals is somewhat greater than the accuracy in reproduction for both the main group and for the music students. This is because of the general tendency to sharp the reproduction. With both men and women the largest C.E.'s are to be found in the test for voluntary control. This may be accounted for in terms of the novelty of the task, the overestimation of small intervals, and the probable genuine difficulty of the task. The variability of the group as a whole is greatest on the interval test, least on the reproduction. This is due chiefly (as will be pointed out later) to individual differences in interval concepts.

Individual differences. Individual differences in accuracy are

marked in all of the tests. In reproduction some individuals flat consistently, others sharp to an equal extent. In terms of general accuracy (A.E.) some singers are more than ten times as accurate as others. Individual records of the C.E.'s for interval singing show in general three types of error: (1) consistent general flatting or sharping throughout, (2) systematic errors on particular notes of the scale, and (3) general and inconsistent deviations. It is on the basis of such analyses of individual errors as these that a program of training in accuracy should be built. Great individual differences in the general accuracy of singing are apparent also.

The most interesting type of individual differences which occurs in the test for voluntary control is to be found in the differences in C.E. of the singing. It is quite apparent that some of the *O*s were able to imitate accurately each of the intervals presented, while others, either through auditory defect or lack of motor control, failed.

Interpretations. Aside from the theoretical and psychological interest of the tests as measures of a certain aspect of the efficiency of the total psychophysical organism, their value centers about two major points, their use as training devices, and their place in a program of prediction of aptitudes. The place of test techniques in a program of diagnosis and training has been discussed by *Seashore* in the manual (23). Before the tests shall have achieved a definite place in a program of prediction of talent, they must be evaluated on the basis of at least four considerations, which may be put in the form of questions. To what extent are the abilities measured by the tests susceptible to training? What degree of control of pitch is required of the accepted artist? To what extent does control of pitch as measured by the tests correlate with control of pitch in actual singing situations? To what extent are the tests specific, that is, to what extent do they make a unique contribution to the total description of the singer's equipment?

Improvement with training has been shown in all three of the tests for vocal control of pitch when practice has been given

with knowledge of results. *Knock* (11) reports net gains from 21 to 42 per cent in twelve *O*s as a result of an intensive training series in the reproduction of a standard and in the singing of three intervals. *Seashore* and *Jenner* (24) report gains from 42 to 60 per cent for reproduction and three intervals under similar conditions. The gain for voluntary control (minimal change) was 26 per cent. It seems quite certain that training with immediate knowledge of errors, results in gain in the accuracy of singing, particularly in the control over intervals, and that vocomotor control does not fall strictly within the category of simple elemental abilities. For testing of talent, therefore, the tests must be evaluated in other terms, such as the amount of gain within a limited period of practice, with due regard to individual differences at the initiation of training, or in terms of the limits of training in relation to the required standards for acceptable singing.

It would hardly be questioned that purity of intonation is one of the most essential requirements for artistic singing, but the exact degree of control of pitch required in the artistic singer is as yet undetermined. The problem is not entirely a simple one, since such factors as the perception of pitch in the vibrato and conscious deviations for artistic effect must be taken into consideration in the final evaluation, although it is apparant that the production of artistic deviation in pitch, for example, implies a rather high degree of pitch sensitivity and control. All of these problems are susceptible to solution by techniques now available.

The validity of specific measures may be considered both analytically and experimentally. Analytically considered, the three fundamental abilities which the present tests attempt to measure seem to function in singing in a peculiarly intimate way. Reproduction of a tone, and the singing of musical intervals, especially when these are measured in melodic situations, are really samplings from a job analysis of singing. Nor is voluntary control much more remotely connected with the singing act, when one considers the fact that the singer must be able to correct

small accidental errors in intonation, and produce small deviations from the regular tone in accentuation for artistic effect. Experimentally such tests may be validated by correlating test scores with phonophotographic or tonoscopic studies of actual singing.

To what extent such tests measure vocal control of pitch uniquely, in a way that can not be predicted with accuracy from more basic tests, such as pitch discrimination, is a problem on which a certain amount of experimental data is available. Correlations based on extensive data have been computed by *Seashore* and *Mount* (25), *Miles* (16), and *Brennan* (4). While the results of these writers are not in entire agreement, the general trend of the data indicates that there is a positive, but relatively low, correlation between scores in the vocal tests and several sensory capacities. The highest correlations reported are of the order of .50. The certainty of these values are, however, impaired by the fact that no test reliabilities are given. The results from the tests of interval singing are particularly open to question since the much more extensive samplings on the ability obtained in the present research failed to give an entirely satisfactory reliability. The following correlations were obtained from the present series on 27 cases between scores on the *Seashore* tests and two vocal tests:

Pitch discrimination and reproduction	.18 P.E.	.12
" " " interval	.44 P.E.	.10
Tonal memory and reproduction	.57 P.E.	.09
" " " interval	.56 P.E.	.09

But for purposes of prediction, correlations of the order of .50 give a reduction in the standard error of estimate over mere guessing of only 13.4 per cent. Hence the present trend of the evidence suggests that tests of the basic sensory capacities may well be supplemented by valid tests of motor control.

V. General Summary

The present study has had three primary objectives: (1) the development of a model of the tonoscope which would combine a degree of accuracy adequate for general testing and purposes

of practice with the advantages in convenience and portability which a model smaller than the standard laboratory model possesses, (2) a critical and experimental analysis of test procedures in the measurement of control of pitch of the voice, and (3) the development, for purposes of quantitative evaluation, of a series of tests of the three basic abilities in vocal control of pitch. The essential findings on the three problems may be summarized as follows:

1. The mechanical arrangement of the portable tonoscope has been developed to the point where it may be used for purposes of testing or practice under conditions which in no way hamper the singer in tonal production. The errors introduced by irregularities in the speed of the motor vary consistently below one per cent, the errors in the scale being consistently smaller than the finest unit of reading used in ordinary tests of singing. The pitch of sung tones may be read by practised individuals with accuracy in terms of twentieths of a tone.

2. On the basis of a critical survey of the literature and some supplementary experimental measurements, and within the restricted samplings available, the following factors may be said to affect the accuracy of singing to a greater or less degree: in reproduction, the timbre, intensity, and pitch of the standard tone, and a large temporal interval between standard and reproduction; in all tests, vowel quality, range of voice, stereotypy, and voice intensity; in the singing of intervals, the pitch of the reproduction, the melodic situation, and the progressive error in scale passages. It is probable also that certain subjective factors, such as emotion, knowledge of results, and motivation affect the score.

3. The reliability of the test for reproduction of a tone, for a sampling of 20 trials at one vocal range was .94, P.E. .02, for 27 cases. The reliability of the test for singing intervals, based on samplings of all the notes in the major scale sung in scale and melodic settings, was, for the C.E., .67, P.E. .03, for the A.D., .34, P.E. .05, for the A.E., .64, P.E. .03. The reliability of the test for voluntary control, in which the gross A.E. in the

imitation of the intervals on the pitch record, side A, of the *Seashore* " Measures of Musical Talent " was taken as a measure, was .98, P.E. .002.

4. The following group errors were noted: a general tendency to sing sharp on the reproduction, especially in the case of the women tested; a general tendency in terms of deviations from the tempered scale toward singing the smaller intervals with greater accuracy than the larger, and a general tendency to sharp the leading tone and the octave; in voluntary control, a general tendency to sing the smaller intervals too large.

5. Pronounced individual differences were found in the ability to reproduce a standard tone, and in the ability to imitate small intervals. In the singing of musical intervals the occurrence of characteristic types of error for a given individual was marked.

VI. Appendix A: Supplementary Experiments [21]

A. Reproduction of the electric tone generator. Nine *O*s sang 30 reproductions each, under identical conditions, of the tone generator and of a tuning fork of the same pitch. Particular care was taken to keep the pitch the same by frequent checking of the speed of the tonoscope and the frequency of the fork by the stroboscopic technique. The trials were so divided that the reproductions of each tone alternated with groups of 15 trials each in order to avoid any progressive differences in the reproductions. The data are summarized in Table VI, in parts of a tone. A to E are men, F to I, women.

The tone generator is reproduced flatter than the tuning fork by an amount that is obviously not significant. The constant errors of the *O*s on both tones are much greater than the differences between tones. Introspective reports from the *O*s indicated that the quality of the tone generator was

[21] In these experiments a superior group of *O*s was used, "superior" in the sense that they were above the average in musical sensitivity and motor control, and were nearly all trained to some extent in introspection. This procedure is defended on the following basis. In studies such as these, where the aim was the measurement of the effect of certain specific variables and sources of error on vocal control of pitch, experimentation is greatly facilitated by the elimination of irrelevant factors. With an inferior *O*, it is impossible to say whether a certain result is due to the operation of the factor under consideration, or merely to his lack of sensory capacity, motor control, or ability to follow directions. The net result of such lack of selection in *O*s is merely to obscure the issue. The statistical treatment of these problems may be considered on two bases, the internal consistency of results, and through formulæ for the standard error of differences. Where the data have been sufficient, the latter criterion of significance has been used, from the formula $\sqrt{\sigma^2_{\text{av. 1}} + \sigma^2_{\text{av. 2}}}$ which is the most rigorous of the formulæ, taking into account both sampling and response errors.

practically indistinguishable from that of the tuning fork and resonator at the low intensities used in the test.

B. Reproduction of low-pitched tuning forks. The problem of the accuracy of reproduction of low-pitched tuning forks was attacked in the following manner. Eight men above the average in general musical ability were required to reproduce the pitch of three tuning forks as follows: (1) a wire and disc tuning fork of 128 ~, reproduced at the same level, (2) a 256 ~ fork, reproduced at its own level, and (3) a 288 ~ fork, reproduced an

TABLE VI. *Comparison of reproduction of tuning fork and electric tone generator*

O	Measure	Reproduction of tuning fork	Reproduction of tone generator	Difference (fork minus generator)
A	C.E.	.05	—.04	.09
	A.D.	.09	.08	
B		.07	.05	.02
		.05	.04	
C		.03	—.02	.05
		.04	.03	
D		—.21	—.19	.02
		.06	.08	
E		.04	.05	—.01
		.04	.05	
F		.14	.13	.01
		.03	.03	
G		.05	.04	.01
		.05	.04	
H		—.11	—.11	.00
		.03	.05	
I		.11	.05	.06
		.06	.09	
A.M.		.01	—.02	.03
$\sigma_{\text{distr.}}$		.10	.09	

octave lower. Each individual was instructed to sound the fork softly, to listen carefully and to use any means possible such as humming with the fork, to reproduce the tone accurately. The tones were sung on the vowel a. Forty-five trials were made on each fork, in a rotating order.

Several *O*s complained at once of the difficulty of locating the pitch of the lower fork. Two said they could hear two pitches and were uncertain which to use. Table VII gives the data for the three situations, in terms of C.E., and σ for each tone. The results are in parts of a tone.

Relative units were chosen for the data in this table in order to make the results comparable. The group error was much greater in the reproduction of the low fork, both in terms of C.E. and in individual variability. An examination of the table will show the individual differences present in the

situation; it is apparent that, while some individuals are able to reproduce low-pitched tuning forks with an accuracy comparable with their reproduction of forks of higher pitch, some individuals of rather high musical sensitivity are affected in a decidedly adverse manner by the use of low forks.

C. Effects of vowel quality on reproduction. In measuring the effect of vowel quality on reproduction, tuning forks of C (256 ~) and G (384 ~) were used as stimuli. The forks were held before a resonator at a uniform distance from the *O* and were sounded for 2 seconds. The following vowels were used: *i* and *e*, to represent the frontal vowels, *a* and ɔ: to represent the neutral vowels, and *o* and *u* as the back vowels. Each *O* sang ten trials on each vowel at each pitch level, the men reproducing the pitch an octave below the standard. In order to break up the tendency toward stereotypy and to prevent fatigue from affecting the reproduction on one vowel group

TABLE VII. *Accuracy of reproduction of tuning fork tones of different pitch*

O	Measure	128 ~ fork	256 ~ fork	288 ~ fork
A	C.E.	.23	.11	.07
	σ	.21	.06	.09
B		—.11	—.02	.02
		.21	.06	.08
C		.37	.03	.00
		.14	.08	.01
D		.35	.10	.08
		.23	.08	.12
E		.03	—.17	.12
		.21	.08	.07
F		.08	.05	.11
		.08	.05	.07
G		.03	—.02	.11
		.11	.08	.07
A.M.$_{C.E.}$		.14	.01	.07
A.M.$_{\sigma}$		.17	.07	.07

more than another, the trials were given in the following order: *a* at 256 ~, *a* at 284 ~, *i* at 256 ~, *i* at 384 ~, *u* at 256 ~, *u* at 384 ~, *o* at 256 ~, *o* at 384 ~, ɔ: at 256 ~, ɔ: at 384 ~. The *O*s had no knowledge of the purpose of the experiment and were ignorant of the existence of any systematic effect of the vowel on reproduction. The C.E.'s and A.D.'s for each *O* in each situation are given in Table VIII. The data are given in ~ to facilitate comparison with the results of *Miles* (16). The *O*s A to G are men, H to L, women.

The order is, from highest to lowest for the group as a whole, *i* and *e* sung sharp, *a*, ɔ: and *u*, neutral, with *o* sung lowest. Since the procedure in both the present experiment and that of *Miles* (16) was so nearly identical, the results from both have been thrown into a single distribution for the purpose of determining the significance of the difference between the extreme vowels *i* and *o*. Combining the results for the *O*s of Miles in reproducing a 182 ~ fork, and our own, the $^{D}/_{diff.}$ quotient is 3.5, indicating a considerable

TABLE VIII. *Effect of vowel on reproduction*

O	Measure	C						G					
		i	*e*	*a*	*ɔ:*	*o*	*u*	*i*	*e*	*a*	*ɔ:*	*o*	*u*
A	C.E.	4.5	3.4	2.4	2.6	1.8	2.0	4.5	4.0	2.5	2.9	1.6	2.6
	A.D.	.6	.8	.5	.5	.3	.4	.5	.2	.5	.5	.5	.6
B		5.4	6.2	1.5	3.7	3.1	4.4	5.5	3.9	1.6	2.2	.7	.8
		.9	1.0	.6	.5	.7	1.1	.9	.7	.6	.3	.7	.5
C		1.0	1.0	2.2	1.7	1.3	.6	5.2	4.2	3.1	2.9	2.7	3.0
		.1	.1	.8	1.2	.8	1.2	.8	.6	.5	.7	.6	.1
D		1.8	.3	.5	.5	—.4	0.0	1.5	.5	—1.0	—.9	—1.3	—1.4
		.3	.9	.5	.5	.5	.2	.6	.6	.6	.4	.6	.7
E		.7	2.5	4.8	1.2	.6	1.3	2.6	2.1	.6	.5	.1	.6
		.4	.8	.5	.3	.5	.6	.8	.5	.9	.5	.2	.5
F		3.1	1.2	—2.2	—1.6	—1.0	—2.8	3.2	.8	—1.1	—1.3	—1.1	—1.7
		.5	1.4	1.0	.9	.6	.8	.5	.5	.5	.8	.5	1.1
G		2.1	1.1	.9	0.0	—.1	.2	2.1	1.5	—.1	—1.0	—.8	—.1
		.4	.4	.7	.6	.5	.8	.5	.5	.4	.2	.4	.5
H		7.2	6.4	2.8	3.0	—.4	3.0	7.0	6.2	2.4	3.6	—1.4	1.2
		1.2	1.2	2.0	1.2	1.2	1.2	1.4	.6	1.2	1.0	1.2	1.4
I		9.4	9.2	2.6	1.0	1.4	5.6	13.2	12.4	6.2	6.2	5.0	7.8
		.8	.9	1.2	.9	1.2	.3	1.2	1.0	1.0	1.0	1.0	1.2
J		11.8	10.2	6.2	7.0	5.8	5.8	14.0	9.4	6.8	6.8	5.4	4.2
		.9	.7	1.4	.9	.6	.8	.8	1.4	1.6	1.0	1.2	1.9
K		8.4	5.8	5.2	4.8	3.0	5.2	7.8	7.8	5.2	6.0	5.2	6.4
		.6	.7	1.4	1.4	1.2	1.0	.6	.6	1.2	.8	1.0	1.0
L		2.8	.6	.2	—.4	—2.6	.2	3.0	2.8	.2	—1.0	—2.6	.2
		.4	.6	.4	.9	.6	1.0	.4	.8	.4	.8	.8	1.0
$A.M._{C.E.}$		4.9	4.0	2.3	2.0	1.0	2.0	5.8	4.6	2.2	2.2	1.1	2.0
σ_{group}		3.4	3.3	2.2	2.3	2.1	2.7	3.8	3.5	2.6	2.7	2.7	2.8

degree of certainty that the differences between the extreme vowels are significant.

D. Changes in vocal intensity in interval singing. The effect of changes in the intensity of the voice during the singing of an interval was measured as follows. *O*s were required to sing two intervals with *crescendo.* The intervals selected were the major third and the perfect fifth. The instructions were to sing the lower tone softly, on the syllable 'la', and to swell out into the second tone with a large *crescendo.* The second reading was taken after the *crescendo* had ceased and the singer was holding the pitch as steadily as possible on the upper tone. Quality of voice was kept as constant as possible. Five men and four women were used as *O*s. Each sang 10 trials on each interval. The mean of these trials was compared in each case with the mean of 20 trials on the same intervals, sung in isolation at a different time, with all factors held constant, the *O*s being under the instruction to sing the interval as accurately as possible. The results are presented in Table IX in parts of a tone, the men being listed first.

TABLE IX. *Effect of changes in intensity on the singing of interval*

		Third			Fifth		
O	Measure	Normal	Crescendo	D	Normal	Crescendo	D
A	C.E.	—.09	.06	.15	—.04	.03	.07
	A.D.	.03	.04		.09	.04	
B		—.02	.09	.11	.02	.15	.17
		.03	.05		.03	.03	
C		.14	.22	.08	.02	.18	.16
		.04	.04		.04	.02	
D		—.11	.20	.33	—.10	.15	.25
		.09	.07		.08	.03	
E		.09	.06	—.03	.00	.14	.14
		.06	.04		.06	.03	
F		.02	.16	.14	.15	.15	0.0
		.05	.07		.04	.06	
G		.09	.05	—.04	.19	—.11	—.29
		.05	.06		.05	.07	
H		—.10	.01	.09	.07	.12	.05
		.02	.08		.04	.07	
I		.15	.25	.10	.10	.21	.11
		.04	.04		.04	.03	
$A.M._{C.E.}$		.02	.12	.10	.05	.10	.05
σ_{group}		.09	.09		.07	.09	

The number of cases is insufficient for statistical examination. The general trend in most cases is for the tone sung loudest to be sharped. It will be noted that in three cases there was a tendency for overcompensation, with the result that the interval was sung flatter with the *crescendo.*

E. Range of voice and interval singing. A measure of the influence of the range of the voice on the singing of interval was obtained by having a number of *O*s sing the same interval at a low but comfortable range, at the middle of their range, and at a pitch that was close to the extreme upper limit of their range. The major third was used for this measure. The instructions were to sing the syllable 'la', in the most accurate major third possible. Nine *O*s participated. The results are presented in Table X, in terms of parts of a tone. A to E are men, F to I, women.

TABLE X. *Accuracy of singing the major third at different vocal ranges*

O	Measure	Low easy	Middle	High
A	C.E.	—.09	—.07	—.11
	A.D	.03	.04	.05
B		.02	—.02	.01
		.03	.04	.03
C		.14	.13	.10
		.04	.03	.04
D		—.11	—.10	.01
		.09	.06	.01
E		.09	.08	0.00
		.06	.05	0.00
F		.02	.01	.00
		.05	.04	.04
G		.09	.09	—.04
		.05	.03	.05
H		—.10	—.08	—.06
		.02	.03	.05
I		.15	.12	.06
		.04	.05	.06
$A.M._{C.E.}$		.02	.02	—.03
σ_{group}		.09	.09	.06

There is some tendency to flat the high third. The difference between the low, but comfortable, range and the middle range is negligible.

F. Influence of the melodic situation on intonation. In the present study the influence of the melodic situation on intonation was measured under the following conditions: (1) singing the major scale upward; (2) singing the major scale downward; and (3) singing the same notes in a natural setting as part of a melody. From the two familiar songs, "America" and "Annie Laurie", a selection of tones was made which included all of the notes of the major scale. The first, third, seventh and ninth

notes of "America" yielded the first four tones of the scale, and the third, fifth, seventh, eighth and tenth tones of "Annie Laurie" gave the tonic, the octave, and the seventh, sixth and fifth notes of the scale. An evaluation of the effects of the melodic situation was derived from the comparison of the mean sung pitch of the notes in the three situations.

Sixteen *O*s took part in the experiment, eight men and eight women. There were ten trials on each note of the scale in each situation. The value of each interval was calculated from the tonic as a base. The results are presented in Table XI in terms of parts of a tone.

Table XI is to be read as follows: "The mean value of D (supertonic) for the 16 *O*s was, in the 'scale up' situation, plus .03 of a tone, *etc.*" Table XII shows the significance of these differences in terms of the $D/\sigma_{diff.}$ quotient.

TABLE XI. *Mean sung value of the notes of the major scale in different melodic situations*

Situation	Measure	D	E	F	G	A	B	C
Scale up	C.E. $_{group}$	.03	.02	—.01	.01	.03	.16	.07
	σ_{group}	.08	.08	.11	.08	.10	.17	.10
Scale down		.06	.05	.05	.05	.02	.10	.02
		.08	.11	.08	.08	.08	.10	.10
Melody		.01	—.01	—.04	.08	.04	.15	.09
		.06	.05	.10	.08	.07	.12	.08

TABLE XII. *Significance of the differences in intonation in different melodic situations:* $D/\sigma_{diff.}$

Situations Compared	D	E	F	G	A	B	C
Scale up and Scale down	1.07	.91	1.92	1.42	.31	1.44	1.43
Scale up and Melody	.83	1.25	.83	2.50	.33	.35	.62
Scale down and Melody	2.08	2.14	2.81	1.07	.66	1.20	2.19

Some of these differences approach statistical significance indicating that the melodic situation does affect the singing of interval. These differences, however, do not follow strictly the laws laid down by *Abraham* (1). The leading tone is sung sharp, in the "scale up" section, but is also sung sharp in both the "Annie Laurie" and the "scale down" sections. It is sung in the "Annie Laurie" section more like the "scale up" than the "scale down"

section, though the direction of melodic movement is downward. The notes E and F are sung flat in the melody, though the direction of melodic movement is upward. The G is sung sharp in "Annie Laurie", though the direction of movement is downward. This may be due to the octave up being sung sharp, but the A immediately before the G is not sung as sharp as is the G. While the sampling of situations in this series is not adequate for the derivation of general principles, it has been shown that the melodic situation has a definite influence, in some cases, on the singing of intervals, and that these influence are not generally reducible to a simple law, but are decidedly complex in character.

Values for the intonation of the same interval in different scale situations, can also be obtained from the data if intervening tones are disregarded. For the purposes of measurement the following sampling of the intervals was chosen:

Perfect fifth	Perfect fourth	Major third
C–G	C–F	C–E
D–A	D–G	F–A
E–B	E–A	
F–C	G–C	

Table XIII presents the results of this series. The data are in the form of deviations for each interval, classified according to the note of the scale which was the lower note of the pair, and according to the situation. The table is to be read as follows: "In the 'scale up' situation, the perfect fifth having C as its lower tone, was sung (average for all *O*s) 1/100 tone sharp," *etc.*

TABLE XIII. *The effect of melodic situation on the value of intervals as sung*

	V				IV				III	
Situation Measure	C	D	E	F	C	D	E	G	C	F
Scale up $C.E._{group}$	.01	.00	.14	.08	—.01	—.02	.01	.06	.02	.04
σ_{group}	.07	.09	.13	.09	.09	.09	.10	.06	.07	.05
Scale down	.05	—.04	.05	—.13	.05	—.01	—.03	—.03	.05	—.03
	.07	.06	.06	.11	.07	.06	.09	.06	.09	.06
Melody	.08	.03	.16	.13	—.04	.07	.05	.01	—.01	.08
	.08	.08	.10	.06	.08	.07	.06	.06	.04	.08

A number of these differences are rather large. Table XIV gives the significance of the differences in terms of the $D/\sigma_{diff.}$ criterion for the cases where the deviations are greatest.

TABLE XIV. *Significance of the differences shown in Table XIII: $D/\sigma_{diff.}$*

	Interval									
	V				IV				III	
Situation	C	D	E	F	C	D	E	G	C	F
Scale up Scale down								3.7		
Scale up Melody	2.3					2.7				
Scale down Melody		1.4	2.4	3.9	2.8		1.9			3.5

Most of the more apparent differences are between "scale down" and melody. All of the differences are due to certain consistent errors in the melodic situations as shown in Table XI. For example the difference between "scale up" and "melody" on the interval C–G is due to the fact that the G is sung sharp in "Annie Laurie".

When the mean values for these intervals in all situations are considered the greatest differences are found between th fifth up from E and all the other values for the fifth. This is because of the universal tendency to sharp the leading tone. The results of this experimental series indicate that the scale position of the notes influences the singing of intervals in a melodic situation. They suggest that such scale relationships, as tonic, supertonic, leading tone, *etc.*, may be more important in determining intonation than the pure interval concepts between notes, especially between those separated by intervening tones.*

Influence of variant tone on pitch of reproduction in voluntary control. Reversing the direction of change in pitch in voluntary control suggests the problem of the effects which singing the variant tone first has on the pitch of the reproduction of the standard tone. This was tested by comparing the pitch of the reproduction when the standard tone came first with the pitch of the reproduction of the standard when the variant tone preceded it. Records were taken of 14 *O*s in the imitation of the first five steps in the *Seashore* pitch record. In every case the reproduction of the standard tone was somewhat higher when the variant tone was sung first. The mean pitch for the reproduction of the standard when it occurred first was .06 of a tone sharp, with a group σ of .16; the mean pitch of the reproduction when the standard occurred last was .12 of a tone sharp, with a group σ of .17. The difference cannot be said to be significant.

VIII. Appendix B. Tabulations of Test Results.

Tables of the results for all of the individuals taking the three tests are presented here. Table XVI presents the results for reproduction of a tone for the three groups, in terms of C.E., A.D., and A.E. Tables XVII, XVIII, and XIX present the results for singing of interval for the three groups in terms of the same measures. Tables XX and XXI present the results for the 18 *O*s who took the revised test for voluntary control. The *O*s are numbered to correspond in the test for reproduction and interval, but since the group who took the test for voluntary control was made up largely of different individuals, the numbering in this table does not correspond with the numbering in the other two tables. All of the results are in terms of parts of a whole tone.

* The occurrence of the "flatted fourth" and the "sharped sixth" in the singing of these individuals presents an interesting analogy to the preference reported by Meyer. (Meyer, M. Elements of a psychological theory of melody. *Psychol. Rev.*, 7, 1900, 241–273.) The sharping of the fifth differs, however, from his results.

TABLE XVI. *Test results: reproduction of standard tone*

O	Measure	Men	Women	Music School Students
I	C.E.	—.01	.25	.00
	A.D.	.05	.05	.00
	A.E.	.10	.25	.01
II		.15	.02	.01
		.11	.04	.02
		.15	.03	.01
III		—.01	.19	.03
		.03	.10	.04
		.03	.20	.03
IV		.11	.20	.02
		.04	.05	.03
		.11	.20	.02
V		.01	.02	.12
		.02	.05	.05
		.01	.09	.12
VI		.03	.10	.03
		.05	.04	.06
		.03	.10	.03
VII		—.14	.02	—.03
		.07	.04	.04
		.14	.03	.04
VIII		—.08	.00	—.02
		.05	.03	.03
		.08	.03	.02
IX		—.01	.00	.02
		.05	.02	.03
		.04	.03	.02
X		.00	.05	.00
		.00	.06	.00
		.01	.06	.01
XI		—.05	.34	.01
		.06	.05	.02
		.08	.34	.02
XII		—.05	.02	—.02
		.11	.06	.03
		.08	.06	.06
XIII		.03	.25	.01
		.04	.05	.01
		.03	.25	.01
XIV		.09	.02	.00
		.05	.02	.05
		.10	.02	.06
XV				.00
				.00
				.00

O	Measure	Men	Women	Music School Students
XVI				.00
				.00
				.00
XVII				.04
				.05
				.04
XVIII				.03
				.04
				.03
XIX				.05
				.05
				.05
	$A.M._{C.E.}$	.01	.09	.06
	$\sigma_{C.E.}$	.07	.14	.10
	$A.M._{A.D.}$	.05	.05	.03
	$\sigma_{A.D.}$	.03	.02	.06
	$A.M._{A.E.}$	.07	.12	.04
	$\sigma_{A.E.}$	.05	.10	.03

TABLE XVII. *Test results; interval singing; men*

		Interval tone						
O	Measure	D	E	F	G	A	B	C
I	C.E.	—.12	.11	.06	—.06	.01	.19	.06
	A.D.	.10	.12	.13	.10	.07	.11	.15
	A.E.	.14	.12	.13	.12	.07	.19	.14
II		.04	—.05	—.01	—.18	—.07	.05	.19
		.14	.25	.20	.11	.15	.26	.15
		.14	.26	.20	.22	.17	.25	.24
III		.02	.05	.13	—.03	.09	.31	.11
		.07	.10	.08	.03	.10	.10	.13
		.07	.11	.14	.04	.12	.33	.14
IV		.11	.05	.01	.11	.10	.25	.11
		.04	.10	.04	.09	.05	.09	.11
		.12	.10	.04	.14	.10	.25	.12
V		—.06	—.09	—.04	—.09	.04	.12	—.06
		.09	.09	.10	.14	.13	.13	.25
		.10	.14	.11	.18	.13	.16	.22
VI		.01	.05	—.06	.00	—.01	.03	.00
		.09	.09	.07	.09	.04	.05	.06
		.09	.10	.09	.09	.04	.05	.06

		Interval tone						
O	Measure	D	E	F	G	A	B	C
VII		—.11	—.01	.14	.10	.08	.27	.09
		.08	.11	.06	.12	.13	.09	.10
		.14	.14	.15	.16	.13	.30	.14
VIII		—.09	.05	—.14	—.03	—.12	—.05	.00
		.09	.07	.05	.05	.05	.07	.03
		.10	.05	.14	.06	.11	.07	.05
IX		.04	—.02	.03	.03	.08	.25	.13
		.05	.06	.07	.09	.05	.15	.09
		.06	.07	.07	.09	.10	.26	.13
X		—.01	.01	—.09	—.02	.01	.13	.05
		.05	.06	.04	.04	.03	.05	.05
		.04	.05	.09	.04	.02	.13	.05
XI		.06	.01	.05	.07	.16	.25	—.05
		.08	.13	.10	.14	.05	.08	.08
		.10	.17	.09	.16	.16	.25	.10
XII		—.06	—.05	—.04	—.01	—.01	.08	.13
		.10	.13	.11	.11	.09	.11	.10
		.11	.14	.10	.11	.09	.08	.15
XIII		.01	.02	—.01	.04	.07	.23	.14
		.06	.06	.08	.07	.07	.12	.10
		.06	.05	.09	.07	.09	.24	.14
XIV		.01	.07	.06	.12	.11	.24	.15
		.03	.04	.06	.06	.04	.11	.12
		.02	.07	.08	.12	.10	.23	.22
$A.M._{C.E.}$		.00	.00	—.02	—.01	.04	.16	.07
$\sigma_{C.E.}$		.064	.056	.088	.078	.070	.112	.089
$A.M._{A.D.}$		.08	.10	.08	.08	.07	.10	.10
$\sigma_{A.D.}$		.024	.048	.040	.038	.037	.055	.163
$A.M._{A.E.}$		.09	.11	.11	.11	.10	.19	.13
$\sigma_{A.E.}$		.035	.053	.039	.055	.043	.095	.059

TABLE XVIII. *Test results; interval singing; women*

		Interval tone						
O	Measure	D	E	F	G	A	B	C
I	C.E.	—.11	—.11	—.14	—.06	—.15	—.10	—.02
	A.D.	.06	.05	.04	.07	.06	.09	.08
	A.E.	.11	.12	.13	.08	.14	.12	.07
II		.02	.01	—.02	.09	.07	.17	.00
		.08	.12	.14	.07	.02	.06	.02
		.08	.12	.13	.10	.07	.17	.02

		Interval tone						
O	Measure	D	E	F	G	A	B	C
III		.13	.02	.04	—.01	—.03	—.07	—.12
		.05	.11	.10	.07	.07	.08	.07
		.13	.11	.11	.06	.07	.10	.12
IV		.12	.13	.15	.15	.12	.29	.03
		.04	.07	.05	.08	.04	.08	.13
		.12	.15	.15	.16	.12	.29	.14
V		.05	.05	.01	.08	—.16	.13	.02
		.09	.10	.13	.06	.09	.09	.12
		.09	.11	.11	.10	.18	.14	.11
VI		.05	—.03	.04	.04	.03	.14	.03
		.07	.09	.10	.08	.04	.10	.09
		.07	.08	.12	.07	.04	.17	.10
VII		.04	—.07	—.05	.03	.05	.21	.05
		.15	.09	.12	.17	.11	.14	.13
		.15	.16	.12	.18	.13	.26	.16
VIII		.02	.00	.04	.04	.03	.06	.02
		.06	.05	.04	.08	.09	.08	.07
		.06	.05	.04	.08	.10	.09	.07
IX		.02	.02	.02	.00	.04	.10	.02
		.04	.05	.10	.03	.04	.05	.04
		.03	.04	.12	.03	.06	.11	.03
X		—.04	—.02	—.08	.07	—.02	.05	.05
		.09	.11	.12	.07	.11	.13	.09
		.09	.11	.14	.11	.11	.14	.08
XI		.05	.06	.03	.13	.12	.23	.04
		.10	.10	.13	.05	.06	.10	.19
		.10	.13	.13	.13	.11	.23	.19
XII		.01	—.01	—.07	—.03	—.02	.03	.00
		.08	.06	.07	.11	.07	.12	.09
		.09	.06	.09	.11	.08	.13	.08
XIII		.13	.04	.03	.10	—.03	.06	.03
		.04	.11	.16	.04	.11	.25	.12
		.15	.12	.15	.12	.11	.26	.13
XIV		.03	—.05	—.05	—.03	—.04	.00	—.05
		.08	.10	.10	.06	.07	.04	.05
		.08	.12	.11	.06	.07	.04	.06
$A.M._{C.E.}$		.04	.00	.00	.05	.00	.09	.01
$\sigma_{C.E.}$		.058	.057	.068	.061	.081	.066	.044
$A.M._{A.D.}$		.07	.09	.10	.07	.07	.10	.09
$\sigma_{A.D.}$		.028	.024	.036	.028	.032	.049	.042
$A.M._{A.E.}$		.10	.10	.12	.10	.10	.15	.10
$\sigma_{A.E.}$		.032	.034	.026	.040	.035	.071	.046

TABLE XIX. *Test results; interval singing; music school students*

		Interval tone						
O	Measure	D	E	F	G	A	B	C
I	C.E.	—.01	—.01	—.02	—.01	.01	.00	—.01
	A.D.	.02	.04	.05	.03	.02	.01	.02
	A.E.	.01	.03	.04	.02	.01	.01	.02
II		—.08	—.07	—.09	—.09	—.08	—.09	.04
		.09	.04	.05	.06	.04	.04	.09
		.08	.06	.11	.09	.08	.08	.07
III		—.09	—.06	—.13	—.05	—.07	—.05	—.04
		.04	.06	.06	.06	.06	.06	.07
		.09	.07	.13	.05	.07	.04	.06
IV		.04	.00	.17	.09	.12	.18	.30
		.11	.11	.20	.11	.11	.15	.14
		.11	.11	.21	.13	.15	.18	.19
V		.06	.01	.05	.03	.05	.05	.04
		.11	.05	.08	.08	.10	.10	.06
		.09	.05	.07	.05	.10	.10	.07
VI		—.10	—.15	—.18	—.08	—.05	—.05	—.03
		.04	.09	.10	.09	.07	.07	.09
		.10	.14	.17	.11	.08	.09	.09
VII		—.07	—.07	—.07	—.01	.00	—.05	—.05
		.05	.05	.08	.03	.03	.12	.10
		.07	.10	.08	.03	.03	.07	.07
VIII		.09	.07	.12	.09	.18	.19	.08
		.09	.08	.13	.06	.13	.13	.08
		.07	.05	.08	.04	.12	.12	.06
IX		.02	—.04	—.05	—.04	—.05	—.05	—.07
		.06	.06	.07	.05	.07	.05	.05
		.05	.05	.07	.05	.07	.07	.12
X		.11	.07	.11	.05	.09	.06	.04
		.08	.06	.06	.05	.03	.05	.05
		.13	.09	.11	.04	.09	.06	.04
XI		.04	.03	.05	.06	.09	.11	.10
		.06	.05	.10	.06	.10	.11	.13
		.05	.05	.09	.06	.09	.10	.15
XII		.02	—.05	.01	.02	—.05	—.05	—.02
		.08	.08	.08	.05	.06	.05	.06
		.07	.07	.08	.05	.05	.05	.06
XIII		.06	.09	—.08	.05	.04	.03	.00
		.13	.08	.10	.07	.09	.06	.06
		.09	.10	.12	.06	.09	.05	.06
XIV		—.02	—.14	—.08	—.06	.00	.05	.02
		.04	.05	.08	.08	.05	.05	.10
		.03	.14	.09	.09	.05	.05	.10
XV		—.04	—.09	—.06	.00	—.03	—.05	—.05
		.06	.06	.10	.01	.04	.05	.05
		.07	.08	.10	.01	.03	.05	.03

O	Measure	Interval tone D	E	F	G	A	B	C
XVI		.03	.01	.01	.01	.00	.00	.03
		.03	.05	.05	.04	.04	.01	.05
		.05	.04	.05	.03	.04	.01	.07
XVII		.04	.10	.15	.13	.13	.12	.05
		.07	.07	.07	.10	.10	.09	.14
		.12	.11	.15	.14	.15	.12	.15
XVIII		.00	—.03	—.02	—.03	—.04	.01	.03
		.04	.04	.06	.05	.05	.05	.04
		.04	.03	.05	.04	.04	.04	.04
XIX		.11	.09	.11	.04	.07	.07	—.06
		.04	.09	.03	.07	.05	.09	.14
		.10	.07	.10	.06	.08	.07	.14
A.M.$_{C.E.}$		.01	.01	.00	.01	.02	.03	.02
$\sigma_{C.E.}$		.062	.076	.096	.059	.073	.079	.080
A.M.$_{A.D.}$		.07	.06	.09	.06	.07	.07	.08
$\sigma_{A.D.}$		.030	.019	.037	.026	.031	.037	.035
A.M.$_{A.E.}$		.07	.08	.10	.06	.08	.07	.08
$\sigma_{A.E.}$		.030	.033	.042	.038	.038	.039	.045

TABLE XX. *Test results; voluntary control; men*

O	Measure	Set I	II	III	IV	V	Mean
I	C.E.	—.09	—.01	.06	.14	.21	.06
	A.D.	.05	.08	.06	.06	.06	.06
	A.E.	.09	.08	.06	.14	.21	.12
II		.28	.36	.35	.25	.28	.30
		.08	.06	.08	.08	.07	.07
		.28	.36	.35	.25	.28	.30
III		.56	.47	.42	.58	.55	.52
		.21	.08	.09	.08	.06	.10
		.57	.47	.42	.58	.55	.52
IV		—.01	.06	.10	.15	.10	.08
		.04	.04	.04	.06	.06	.07
		.05	.07	.10	.15	.13	.08
V		.07	.01	.05	.06	.04	.05
		.06	.05	.03	.06	.06	.05
		.08	.05	.05	.07	.08	.07

O	Measure	Set I	II	III	IV	V	Mean
VI		—.02	—.02	.05	.05	.09	.03
		.03	.05	.06	.05	.06	.05
		.05	.05	.05	.05	.10	.06
VII		.04	.04	.09	.15	.19	.10
		.04	.05	.05	.02	.04	.04
		.05	.05	.09	.15	.19	.11
VIII		—.08	—.05	.02	.02	.06	—.02
		.06	.05	.03	.03	.06	.04
		.09	.06	.03	.05	.06	.06
IX		.06	.07	.14	.18	.16	.12
		.08	.08	.09	.06	.06	.07
		.08	.08	.14	.18	.16	.13
X		.37	.42	.50	.57	.48	.47
		.08	.05	.05	.05	.09	.08
		.37	.42	.50	.57	.48	.47
XI		.08	.17	.21	.25	.29	.20
		.07	.04	.06	.06	.09	.06
		.08	.17	.21	.25	.29	.20
$A.M._{C.E.}$		.12	.14	.17	.22	.22	.17
$\sigma_{C.E.}$		.19	.18	.13	.18	.16	.17
$A.M._{A.D.}$		.07	.06	.06	.05	.06	.06
$\sigma_{A.D.}$		.03	.01	.02	.02	.01	.02
$A.M._{A.E.}$		.16	.17	.18	.22	.23	.19
$\sigma_{A.E.}$		.16	.15	.13	.18	.16	.16

TABLE XXI. *Test results; voluntary control; women*

O	Measure	Set I	II	III	IV	V	Mean
I	C.E.	—.05	.12	.14	.16	.25	.12
	A.D.	.05	.07	.07	.05	.09	.09
	A.E.	.07	.12	.14	.16	.25	.12
II		—.01	.03	.10	.07	.10	.06
		.05	.04	.07	.08	.08	.06
		.05	.05	.11	.12	.11	.09
III		—.11	—.04	.09	.12	.14	.04
		.06	.06	.05	.06	.04	.05
		.12	.04	.09	.12	.14	.11
IV		—.03	—.02	.06	.09	.17	.05
		.03	.05	.05	.05	.04	.04
		.05	.06	.08	.09	.17	.09

O	Measure	Set I	II	III	IV	V	Mean
V		—.04	.08	.12	.10	.19	.09
		.05	.11	.05	.04	.05	.06
		.06	.13	.12	.10	.19	.10
VI		.10	.12	.16	.16	.20	.15
		.07	.07	.07	.06	.04	.06
		.11	.13	.16	.16	.20	.15
VII		—.18	—.05	.05	.05	.09	—.01
		.05	.03	.05	.03	.03	.04
		.18	.05	.05	.05	.09	.08
$A.M._{C.E.}$		—.05	.04	.10	.11	.16	.07
$\sigma_{C.E.}$		.08	.06	.04	.04	.05	.05
$A.M._{A.D.}$		.05	.06	.06	.07	.05	.06
$\sigma_{A.D.}$		.01	.02	.01	.04	.02	.01
$A.M._{A.E.}$		.09	.08	.11	.11	.16	.11
$\sigma_{A.E.}$		.04	.03	.03	04	.05	.03

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